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Time Required in Developing Selected Arizona Copper Mines

UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. Bureau of Mines.

Information Circular 8702

Time Required in Developing Selected Arizona Copper Mines

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UNITED STATES DEPARTMENT OF THE INTERIOR
Thomas S. Kleppe, Secretary

BUREAU OF MINES
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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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TIME REQUIRED IN DEVELOPING SELECTED ARIZONA COPPER MINES

by

Lorraine B. Burgin [1]

ABSTRACT

This study by the Bureau of Mines documents the leadtime required for preliminary and detailed exploration, development of the mine, and construction of beneficiation and support facilities for selected copper deposits in Arizona. The time for major exploration ranged from 1 to 15 years, time for open pit development (or construction) was 1 to 4 years, and time for underground development was 4 to 8 years; one underground mine presently being developed may require 12 years to achieve production. Construction of the beneficiation plants required 8 months to just over 2 years.

The data are supported by historical facts for each deposit during the leadtime stages from location of claims through exploration, construction, expansion, and leaching. The sequence of development and factors contributing to differences in the time spans are discussed.

Histories are detailed for the Miami, Castle Dome, Copper Cities, San Manuel-Kalamazoo, and Twin Buttes properties; briefly summarized are the Pinto Valley, Miami East, Esperanza-Sierrita, Pima, and Mineral Park Properties. Each mining operation had its own pattern of development, and together they present a source of planning information for the development of other properties.

INTRODUCTION

Time, an important dimension in the growth of most enterprises, is a factor little documented, considered, or analyzed in mining literature. Since profit is the principal motivation in developing a mineral deposit, time must be a significant consideration both because of inflation and because full production must await definition and development of the deposit.

The period from initial discovery through exploration, development, and plant construction to production, generally referred to as "leadtime" (39)[2]

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[1] Geologist.

[2] Underlined numbers in parentheses refer to items in the bibliography preceding the appendixes.

is one of factfinding, evaluations, decisions, and capital expenditures absolutely necessary to the achievement of production capacity at an operating mine. Important factors contributing to this time span include the inherent physical environment (available resources and land), human resources, technology, management goals, demand and price for the major commodity coproducts and byproducts, and the circumstances of unforeseen events.

Implicit in understanding leadtime as it applies to the mining industry is the recognition of land availability problems and the uncertain time factors and sensitive timing required in the acquisition of land. Land uses must be carefully analyzed and categorized so as not to unnecessarily lengthen leadtime in the exploration and production stages. Minerals are unique in that they are nonrenewable and must be sought, found, and extracted where nature placed them. Furthermore, some deposits and areas which were once determined to be submarginal for mining might become economically feasible for production as existing deposits are depleted, and as commodity prices rise or new technology is developed.

This Bureau of Mines study documents the leadtime that was necessary to develop 10 major copper mines, showing for each the failures and successes in relation to time as prices fluctuated, as technology and demand changed, or as new promotional ability and financing were brought to bear. Leadtimes, with explanations of the events bearing upon them, are presented for the Miami, Castle Dome, Copper Cities, San Manuel, and Twin Buttes properties of Arizona; summary information is also presented on the Pinto Valley, Esperanza, Sierrita, Pima, and Mineral Park properties in Arizona.

Historical data were obtained from mining company annual reports, Bureau of Mines and Geological Survey publications, mining journals, the Copper Handbook, and various other published sources. Exact comparisons of leadtimes were not possible owing to the spotty nature of available data; however, enough information was collected and analyzed to substantiate the premise that each mining operation is different, having its own pattern of development.

ELEMENTS OF MINE DEVELOPMENT

Mine development follows discovery, title acquisition, and exploration, but only rarely is the size of an initial discovery adequate to warrant construction of production facilities. Hence the exploratory work--whether geophysics and geochemistry, drill holes, shafts, and adits from the surface, or raises, winzes, crosscuts, drifts, or drill holes from earlier underground openings--must proceed, phase by phase, until the evidence warrants investment in and construction of mine plant, mill, and ancillary structures. Thus the development of a mine proceeds in the sequence of (1) exploration and (2) development for production, with (3) reclamation and environmental protection.

Exploration

Exploration involves locating economic deposits and establishing their size, shape, position, grade, and type. Preceding a broad exploration

program, clear-cut objectives must be established and fundamental questions regarding the availability of land must be answered.

Exploration Objectives

Long-range corporate or individual objectives should be well defined to provide the necessary framework and guidance to the exploration and development program. Such goals should be established before the exploration project begins and then continuously reappraised during its progress.

Among the important factors influencing any decision on the commodity to be sought are (1) market opportunities, (2) potential production capabilities, (3) financial requirements, and (4) political and social implications.

An evaluation of market opportunities should assess the supply-demand potential of various commodities and indicate those for which there exists the greatest margin between the predicted supply and demand. Ideally, the appraisal would note competitors' activities, such as the number of recent successful discoveries, the number of companies currently supplying the commodity, and their degree of activity and exploration budgets. In addition, the impact of foreign imports, from pricing to political stability, should be carefully assessed. The size and profitability of the company making the study should also be compared with the average size of companies in the commodity of interest.

The project would then be examined for its potential and probable productive capacity to determine the stage of production (mining, smelting, fabrication, or fully integrated) that would meet the objectives, budget, and optimum return on the investment. In metal mining the size and grade of the deposit would be considered along with the costs of exploration and development, and the minimum acceptable cashflow.

Avenues of financial assistance would be investigated to ascertain which would qualify within the framework of the stated corporate objectives and provide an optimum return on capital investments. Depending upon the financial status of the company, financial assistance may be required before discovery, or the project may be internally financed until a discovery has been made and proven.

Political aspects would include consideration of the current legislative climate toward the mining industry, including the prevailing tax structure. Social aspects would include potential pollution, reclamation, environmental regulations, and human relations.

The availability of additional areas that might be open for future exploration and later acquisition should also command attention when objectives are set.

Land Availability

Gaining access to a specified area for preliminary and later detailed exploration introduces the complex problem of land availability and acquisition. Access to potential mineralized areas is essential, for successful mines are developed only where mineralization is sufficient for profitable extraction. Time consuming and costly, the sensitive process of obtaining land varies with each project.

Generally, the availability of land will be assessed early in the reconnaissance-exploration period; later, as the area is targeted, the land status is more critically examined. Near the end of the regional reconnaissance, if there are favorable indications of geology or mineralization, ground will be obtained for further exploration. Throughout the life of a mine, the property situation is examined and evaluated, and action is taken towards acquisition or abandonment.

Land acquisition may involve one or more combinations of the following: direct location on public lands (Federal and State); purchase or lease of private ground, or patented and unpatented claims; leases; Indian or State lands; and company mergers or joint ventures with companies and/or individuals. Because circumstances differ, the time for acquisition varies with a myriad of uncertain factors including the unpredictability of dealing with people, financing, and new governmental restrictions.

Proposed and recently enacted State and Federal environmental regulations will inevitably delay access to lands previously open for exploration without severe restrictions. Some States are setting up land-reclamation laws that apply to exploration and exploratory operations. Such States include Colorado, Georgia, Idaho, Iowa, Kentucky, Maine, Montana, Oregon, Virginia, Washington, and West Virginia. The time taken to acquire land will then be extended by the time needed to process applications, permits, environmental impact statements, or licenses; to make technical examinations of the areas; and to allow the companies to submit exploration plans and post bonds where extensive surface disturbance is anticipated.

On public land, any surface-disturbing exploration for minerals covered by the mineral-leasing acts requires approval by the Federal Government (Bureau of Land Management or U.S. Forest Service and U.S. Geological Survey) and involves an application for permit, a technical examination of the area, and approval of the exploration plan. (The mineral-leasing acts, however, do not yet cover minerals locatable under the Mining Act of 1872.) Exploration for any mineral on Indian land is regulated by similar procedures, in addition to consultation with the landowners and the Bureau of Indian Affairs. Prospecting and location of claims under the Mining Law of 1872 are allowed in National Forest Wilderness designated areas until December 31, 1983, but these activities must be compatible with the preservation of the wilderness. Essential use of mechanized transport, aircraft, or motorized equipment is permitted in the search for minerals; however, no operator may construct roads across the wilderness area unless authorized in writing by the Forest Supervisor. As of September 1, 1974, a reasonable amount of prospecting or sampling in

National Forests will be permitted according to the 1974 regulations, and no plan of operations is required to be filed with the District Ranger. A significant disturbance of surface resources, however, requires the approval of a plan of operations. Such disturbances include construction of roads, trails, bridges, and aircraft landing areas. Some operating plans proposed may necessitate an environmental impact statement to be prepared by the Forest Service (76).

Copper is not a leasable mineral, but when prospecting permits or Government leases are required, time must be allowed for approval through governmental channels--an additional uncertain time element. Relating to leased minerals, lack of time becomes a factor; with the governmental announcement that land is open to competitive bidding, the company or individual must almost simultaneously evaluate a specific area and immediately decide whether to acquire it.

Preparation for preliminary exploration may include gaining physical access to the area. A road may have to be built to drill sites or to the mine area where core or bulk samples are to be obtained. Supplies and equipment, water, and power will have to be brought in, or perhaps flown in, depending on the accessibility of the area to be searched.

Assuming environmental requirements are fulfilled and the discovery or indication of mineralization has been made, open ground on public domain (subject to the Mining Act of 1872) must then be secured by claim location or relocation. The time period will depend on the number of claims located, the time needed to perform discovery or location work, the distance to the county recorder's office, investigation into any conflicts of claim ownership, and the registration of the new claims in the county recorder's office. Possessory title is maintained by completing annual assessment work; later (perhaps years later), title to the ground may be conveyed by obtaining a patent from the Bureau of Land Management. In an unstaked area, the location of new claims will probably require less time than when the area lies in or near old mining districts where the land has or may have been staked, for then owners of patented and unpatented mining claims must be found and negotiations made with the owners or their heirs.

In an old district, prospecting or preliminary exploration is an accomplished fact when an individual or company with a large group of claims approaches another with the hope of securing additional financing or expertise for further exploration. Before a detailed program is undertaken, negotiations for land acquisition ordinarily are completed. Acquisition under these circumstances may assume the form of a purchase, joint venture, or merger.

Preliminary Exploration

Preliminary exploration or prospecting is the search for outcrops or surface exposures of mineral deposits and the preliminary investigation carried out along certain broad features of a mineral area to determine whether detailed or final exploration is warranted. This first stage may include

aerial reconnaissance, followed by surface and subsurface investigation, all of which may be termed "prospecting" or "preliminary exploration."

Depending on individual circumstances, the procedure is to select a region for study and then systematically target specific search areas. Regions chosen will probably be near known mineral occurrences. In a study of exploration philosophy, Bailly reported that out of 56 porphyry copper deposits in North America, 39 were discovered since 1950; that 90 percent of these were found in copper mineralized areas recognized before 1950; and that 80 percent were near known deposits (4). Among the other factors to be considered in a regional study are the size and location of the area, the cost of exploration, and the cost of developing any deposit found.

The well-financed project has often been initiated with a literature search, followed by airborne geological and geophysical reconnaissance. Though employed principally in the beginning stages, the geophysical survey may also be coordinated with other techniques in a later, more intensive effort. Because an anomaly discerned by geophysical exploration does not reveal the tenor of the deposit, the survey is used in conjunction with other geological and geochemical exploration procedures. Core drilling, for example, is of major importance in the preliminary evaluation of the geology and mineralization of an area and in making or confirming a discovery. Airborne electromagnetic (EM) surveys, followed by ground EM or other geophysical methods, have been applied in the search for greenstone belts and associated massive sulfides. Of the various ground methods, the induced potential (IP) has been the favored tool for some of the prophyry coppers in Arizona, New Mexico, and Nevada.

Only an indication of the time periods required for various surveys appears in the literature; the resulting information gaps allow only estimates of these intervals and relationships. The time element in locating new deposits by exploration geophysics is noted in the following examples.

In the Pima mining district, geophysical techniques were used to find the copper ore body of the Pima mine. Prospecting began after a thorough literature search focused attention on the Mineral Hill area of the district, where magnetite was a constituent of the ores in the old mines. After both ores and host rocks were tested for magnetic susceptibility, electrical conductivity, and density, a magnetometer survey was instituted. With a 400-foot grid and readings taken at 12.5-, 25-, or 50-foot intervals, a magnetic anomaly was detected in previously unexplored territory. The results were checked and corroborated with an electromagnetic survey and a self-potential survey. Extended over 7 months, these surveys included mapping and interpretation. The magnetometer 2-man crew read between 60 and 70 stations in 8 hours; the electromagnetic 3-man crew read between 30 and 40 stations in 8 hours (72). Recently, the average surveying rate on large projects utilizing ground electromagnetic systems has been 1.8 to 3 miles per day for a 2- to 3-man crew (59).

Texas Gulf Sulphur's discovery of the Kidd Creek deposit, Ontario, Canada, is an outstanding illustration of the use of airborne geophysical

methods for regional reconnaissance. Scanning more than 15,000 miles, aerial electromagnetic surveys, which began March 1959 and continued through 1961, revealed several thousand anomalies. After the target area for ground geophysical surveys was selected, land negotiation took 2 years before work could commence. Ground surveys in October 1963 pinpointed the drilling area. Copper-zinc mineralization showed in the first drill core in November 1963; by April 1964, drilling confirmed the presence of a minable massive sulfide deposit (16).

The extent of an intensive regional mineral exploration project (financed with the assistance of the U.S. Agency for International Development) was illustrated by Operation Hardrock, begun in July 1967. About 144,000 line kilometers of flying over 90,000 square kilometers of potential ore-bearing regions in India involved airborne electromagnetic, magnetic, and radiometric surveys. The airborne geophysical program was completed in 10 months, (May 1968). The ground projects still in progress during the summer of 1972 had an estimated time schedule of 46 months for reconnaissance ground surveys, beginning January 1968; 37 months for detailed integrated surveys, beginning October 1968; and 32 months for drilling, beginning March 1969. The airborne geophysical survey cost an estimated $1.62 million; exploration equipment services and supplies cost an additional $1.7 million. By October 1971, another $4.4 million was spent on the ground followup program. A total of 11,000 aeroanomaly intercepts were chosen for ground geological reconnaissance; by the summer of 1972 over 700 of these had been investigated by ground geophysical, geochemical, and geological techniques, with 25 targets emerging. Up to that time, 12 had been tested by drills, locating 6 promising prospects--4 copper and 2 zinc-lead (69).

Recently geochemical exploration has included airborne sampling in remote and rugged areas where soil and stream-sediment samples are collected by fixed-wing aircraft and helicopters. More commonly applied are ground geochemical surveys; the methods include regional and local sampling of soils, stream and lake waters, ground water, and certain indicator plants.

The time required for a geochemical survey varies, depending on the area to be covered, and is influenced by the number of samples required to cover the area and the mode of transportation of the field personnel--by foot, horseback, jeep, or helicopter. As an example, Hawkes (26) described a project in Northern Rhodesia where a normal day's sampling for 8 to 10 fieldmen on a reconnaissance soil-sampling expedition was 8 line miles, or 200 samples taken at 200-foot intervals (26). About 11 men in a field laboratory prepared and analyzed 400 to 600 samples daily. In the Philippines, one 2-man team collected up to 55 sediment samples per day at 500- to 1,000-foot intervals. The soil samples were taken at an 18-inch depth every 100 feet. Three 2-man teams collected 100 samples per day in difficult country. Four men performed up to 245 determinations per day in the associated laboratory (26).

The results of the aerial and ground geophysical and geochemical surveys, together with other geologic data, are compared and analyzed to select a favorable target area for more detailed exploration. Further investigation of anomalies may indicate the viability of a project.

For verification of the geological structure, as well as the type and extent of any mineralization, the next step in prospecting will include testing and sampling of old prospects and mines in the target area and exploring new territory by means of drilling, shaft sinking, or tunneling.

Preliminary exploration, if successful, would conclude with an indication of mineralization, or possibly with a discovery sufficient to encourage acquisition and further exploration and delineation of adequate ore reserves.

Discovery and Acquisition of the Mineral Deposit

"Discovery" as generally used by the mining industry may be described as the knowledge of the presence of valuable minerals within the lines of the claim location, or in such proximity thereto as to justify a reasonable belief in their existence. This definition of discovery, however, is not adequate for legal purposes. As used in this report, discovery could also be a point in time when the valuable mineral, ore deposit, or mine becomes known to the entrepreneur. The actual discovery of the deposit may have occurred many years before, and the mine life cycle of preproduction, production, and abandonment may have been repeated several times.

The time required to make a discovery must be somewhat generalized. Preliminary exploration by the early prospectors depended on surface indications of mineralization--a gossan, an outcrop of a fissure or a vein, or the flash of yellow metal in a gold pan, and the location of mineralization then required acquiring the land by location with a placer or lode claim and its proper registration. Basically, the same procedures are followed by the contemporary searcher, except that the deposits are more obscure and the techniques for finding a new deposit have consequently become more sophisticated. The selection of a target area for prospecting may require a longer period for analysis, including regional and local reconnaissance and analysis, preliminary exploration, discovery, and exploration.

Preliminary exploration for and discovery of a valuable mineral, or preliminary examination of a known deposit, is followed by evaluation or analysis of the results, a preliminary feasibility study, and the acquisition of the deposit for further exploration. After the smaller target area has been established, access to the area must be acquired either by claim location and its proper registration, by lease and option to purchase from private owners, or by lease from the State or Federal government.

If the mineral (potassium, sodium, phosphate, sulfur, coal, oil, gas, etc.) is subject to the Mineral Leasing Acts, acquisition by leasing from the Federal Government will depend on compliance with Federal regulations. Discovery of these minerals on a prospecting lease will allow the discoverer some privileges for a continued lease. All minerals, however, are now subject to recently enacted State and Federal laws and regulations. The preliminary exploration period thus has been extended by the amount of time needed for the Government agencies to review applications, examine the areas proposed for exploration, make reports, and approve or reject plans.

The time required for acquiring a mine by direct purchase will depend on many factors including asking price, available financing, and title clearance. Because of valuable factors negotiations may take days, months, or years, with the financially competent companies better able to wait.

Acquisition by lease and option to purchase presumably will have begun in the preliminary exploration period. Negotiations, however, may begin at any stage, often depending on the financing needed to continue exploration or construction.

Preliminary Evaluation and Examination

Before firm commitments for acquisition or detailed exploration, a preliminary evaluation is made to determine the type and extent of the mineralization and whether the deposit can be profitably mined. Included would be a study of applicable mining and beneficiation methods; a survey of markets, labor conditions, Government policy, tax structure, and tariffs; and a review of other factors affecting the economics of the operation.

The preliminary evaluation and examination may include a study of a known mineralized area brought to the attention of the company by a prospector, a syndicate, or another mining company. Also, reexamination of a known mineralized area may be warranted periodically because of improved technology, improved market conditions, or additional information.

Numerous mineral occurrences are examined, but only a small percentage are eventually developed into profitable mining operations. Cominco Ltd. explored more than 1,000 properties in 40 years. Only 78 of these warranted a major exploration effort, and of the 18 ore bodies developed and brought into production, only 7 were profitable (22).

Between 1939 and 1949 the U.S. Government Strategic Minerals Development Program examined 10,071 prospects, of which 1,342 were worked. Ore-grade tonnage was developed in 1,053 of the 1,342 deposits, but these were not necessarily successful mines. The most significant success from the entire Government program is the San Manual mine in Arizona (35).

The preliminary examination is usually short--a few days, weeks, or several months--and may be done by a company geologist, consulting geologist, or engineering firm. Because the period is short and the total involvement is not large, the property may easily be dropped by the participants before large sums of money are expended for detailed exploration and development.

Although discovery of a mineralized zone may be indicated, the presence of a valuable mineral deposit cannot generally be determined from the preliminary exploration program. If the results are encouraging, a detailed exploration program is designed and performed to collect data required for a final, detailed feasibility study.

Detailed Exploration and Feasibility Study

The detailed exploration program determines the size, grade, and continuity of the ore body, and data are collected for a detailed feasibility study.

Initial exploration is usually surface drilling on a predetermined grid pattern modified by data collected during this exploration phase. Additional underground exploration by shaft sinking, drifting, raising, and drilling confirms grade and quantity of reserves, obtains bulk ore samples, and determines the mining and support characteristics of the host rock. Information derived from bulk samples tested in pilot plants is used to design a plant to obtain optimum recovery of the minerals in the ore.

A detailed feasibility study considers all physical factors that may affect the economics of the operation, including ore reserves, mining and processing methods, power and water availability, tailings disposal, production rates, and markets. Involved are detailed cost studies, analysis of possible alternative decisions, and projected capital requirements and cash flows. Geographic factors including climate, topography, and transportation are evaluated, as well as such sociological factors as living quarters for families, schools, and hospitals, which may have to be provided in remote areas.

Feasibility studies will also assess the environmental aspects within the mine and surrounding area. The political climate--local, national, and international--will be carefully examined because of its impact on all phases of the operation, from exploration and production through marketing of the commodity. Any one of the intangible factors--sociological, environmental, or political--may invalidate an otherwise promising enterprise. Management will weigh the factors revealed in the feasibility studies and decide whether to proceed with the project, hold it in abeyance, or reject it.

A detailed exploration and feasibility study, made for Brenda Mines Ltd., Okanagan district, British Columbia, was described by Chapman in 1970 (9). The study, begun in January 1966, was completed in 15 months under the supervision of Chapman, Wood, and Griswold, Ltd., at a cost of $3,500,000. The work included 72 holes totaling 42,573 feet of diamond drilling and 19 holes totaling 7,323 feet of rotary-percussion drilling. Underground work totaled 1,475 feet of drifting, 400 feet of crosscutting, and 860 feet of raising to confirm reserves by correlating drilling grade and bulk-sample grade. A crushing and screening plant, an automatic sampling tower, an analytical laboratory, and a 100-tpd pilot mill were constructed to test the ore. Also included were studies of power, water, tailings-disposal problems, and markets. Sales were negotiated, the mine and concentrator were designed, reserves were calculated, and an economic analysis was made of the effects of mining rates, pit configuration, metal prices, and metallurgical recoveries. Capital requirements and cash-flow projections were estimated. The high cost of the detailed feasibility study was justified because of the size of the projected operation and the reserves delineated. Mine reserves were estimated to be 167 million tons, with a grade of about 0.19 percent copper and 0.087 percent molybdenum sulfide.

The development of a small mine may commence without a prolonged scientifically engineered study and analysis, if the objective of the owner or developer is to recoup the expenses of exploration as rapidly as possible. Thus, drilling and development are kept to a minimum. In such an operation, the ore is often followed as closely as is commensurate with reasonably good mining practices, balanced against the rapid extraction of the ore.

The detailed feasibility study has become a prime requisite to financial arrangements necessary for constructing the contemporary large-scale mine-mill complex; thus, one of the leadtime variants will be the amount of time required to finance the construction of the mine plant and concentrator.

Development for Production

During the development stage, the ore deposit is prepared for production by constructing mining and milling facilities of design characteristics determined during the feasibility study. Construction follows the conclusion of a financial arrangement such as the sale of company stock, joint venture with another company, internal financing, or bank loan by the established company.

Construction of Mine Plant

Mining methods are grouped into two broad categories, surface and underground; within each category are variations which can be adapted to the characteristics of a particular deposit. Within the limits of safety and conservation, one method will be more economic than the other. Principal factors influencing the selection of the most efficient mining method are the nature of the ore body and country rock (size, shape, composition, and position), safety, economics, and conservation.

Environmental characteristics of the deposit which determine or influence economics are topography, climate, type and thickness of overburden, structure of the deposit (horizontal, folded, or faulted), type of ore body (disseminated, vein, massive, bedded), grade and uniformity of mineralized material, depth to water table, and strength and physical characteristics of the host rock.

Strip mining, open pit mining, and quarrying are the principal ways of recovering materials by surface-mining methods.

Strip mining is used where the mineral deposit is large, uniform, horizontal, and close to the surface. The time usually required for removing overburden before mining commences is relatively short. Reclamation of the area can begin almost immediately as material is removed. Coal, sand and gravel, and phosphate rock are strip-mined.

Open pit mining of many hard-rock metallic deposits, such as copper, iron, or uranium, involves much smaller areas than strip mining, where the bedded deposit can often be followed for miles. The metal mine requiring an open pit type of operation is generally limited in size and often requires many years to

develop. Reclamation of the open pit area does not begin until the last ore has been removed.

Planning for developing a low-grade open pit mine is aimed toward regulating the grade of the concentrator feed, recovering any byproduct from the ore, and metallurgically treating sulfide and nonsulfide material. The close control and the consequences of variations in all phases of the operation from stripping to marketing, including the effects of such items as tax and royalty rates on the economics of the operation, are considered in the planning stages.

Open pit development (53) commences with stripping and transporting the overburden to a waste dump in a nonmineralized, environmentally acceptable area. The shape of the pit will be determined by the results of the exploration and development drill holes and from aerial photographs, topographic and geologic maps, and cross sections. The pit size will be limited by the cutoff grade of the ore, that grade being determined by the cost of mining (excluding the cost of stripping), the cost of beneficiating and marketing the ore, and the market price of the recoverable values in the ore. Many deposits have gradational ore-waste contacts; in these, the ore-reserve size and cutoff grade are mutually dependent. The ore reserve varies with the cutoff grade used; the economic cutoff grade depends on the scale of operation made possible by the size of the ore reserve.

Basic, then, to the open pit mine configuration will be the stripping ratio of ore to waste, pit slope angle, and cutoff grade. The type of ores, property lines, topography, and water, etc., also govern the design of bench heights, road grades, and procedures for mining each specific area of the mine.

Time required for developing an open pit operation is generally directly proportional to the quantity of overburden removed from the ore. Four years' leadtime was required for the removal of an extraordinary large amount, 246 million tons, of waste at the Twin Buttes copper deposit. At the Castle Dome mine, about 14 million tons of overburden was removed in 1-1/2 years; at Copper Cities, over 20 million tons was stripped in a little over 3 years.

The stripping ratio is based on the market price of the commodity. High prices allow a larger pit, whereas lower prices force the extraction of higher grade ores and consequently diminish the size of the pit. The ultimate slope stability is determined by the strike and dip of major joints and faults with respect to the slope face, the physical properties of the material, both surface and underground waters, and the length of time the steepened slopes are allowed to stand.

Computers have expedited planning and production in surface mining; they are almost essential for the rapid collation of necessary mine and mill information including ore reserves, metallurgical and production data, ore-blending possibilities, and costs. Computer programs permit examining alternatives to variously proposed plans for maximum production with minimum cost.

In both open pit and underground mining, the size of the operation, the kind of material mined, and the distance moved directly influence the time and cost of production. The four stages of excavation in both methods involve drilling, blasting, loading, and hauling the material.

The choice of drilling system is related to the available energy or power, penetration rate, bit wear, and cost. The rate of drilling or time required for defining the benches depend on the skill of the driller, the type of drilling equipment, the size of the holes, the circulation fluid, the properties of the rock such as hardness, porosity, moisture and density, the structures encountered (folds, faults, joints, and bedding), location, weather, and experienced supervision.

The physical factors of the rock and the chemical factors of the explosive determine the efficiency of the blasting operations. Time is consumed in locating, drilling and loading the holes. The critical factor timewise, however, is the result and fragmentation, placement, and size of the broken rock directly affect the next stage--loading and hauling of the ore or waste.

In strip mines, the blasted or loosely consolidated material is loaded by large-capacity drag lines, shovels, and wheel excavators; hauling is by truck and/or conveyors.

Refinement of open pit mining techniques allows time intervals to be shortened, by improving blasting methods to achieve maximum efficiency while maintaining slope stability, and by developing rapid loading and hauling of ore and waste. Equipment used includes shovels, bulldozers, scrapers, trucks, trains, and conveyors. The time factor in this operation depends on the size of the pit, the distance to the waste dumps, and stockpile and/or concentrator, road grades, and the size of the loading and hauling equipment. The size of the equipment and the most efficient procedures are engineered for the shortest time factors allowed by mining procedures, bench development, and waste removal.

The trend toward using very large hauling equipment to minimize the transportation time at the mine and from mine to mill has been limited by maintenance problems. Moreover, large equipment was difficult to manage under operating conditions, and trucks idled by repairs caused logistics problems in maintaining adequate feed for the concentrator.

The advantages of the open pit method are greater safety and better working conditions, high recovery, economical extraction of otherwise unrecoverable low-grade ores, larger mechanical appliances, high productivity, flexibility, and effective supervision. Disadvantages are exposure to weather, limitation to moderate depth, removal of large amounts of waste rock and overburden, slope failure, and selective mining of the material.

In the design of an underground mine, important considerations in choosing the mining method are the strength of the wall rock, roof, and floor; the depth of the deposit; width of ore and amount of dilution; shape of ore body and regularity of outline; attitude of the ore body, planes of weakness such

as fractures, and shear and fault zones; and mineralization and alteration which change the structure of the rock and affect its behavior under stress.

Difficulties encountered with increasing depth in underground mines include rock bursts, high temperature, humidity, and dust. Heavy ground necessitates extensive support, machinery must be especially constructed or adaptable to the conditions encountered, and greater depths require larger hoists and pumps to lift ore economically and to remove waste and water. Mining of either very high-grade ores, or large tonnages of low-grade ores or improved development techniques are required to offset the costs created by these factors.

Increased capital costs, increased tonnages, deeper shafts, and high rock temperatures demand more efficient mining methods. Provided planning has been careful and complete, new techniques of shaft sinking and tunneling will shorten the construction period.

A breakthrough in shaft sinking came with the development of the circular shaft-sinking technique and mechanical mucking, using for example the cactus-type grab which greatly increased the speed of putting down large-diameter shafts. Standard practice for manual cleanup previously employed over 50 men per shift; using the new equipment, only 10 men were required for the operation. The circular shaft provided an improvement in ventilation, structural strength, and the ability to sink through highly fractured zones and water courses. The development of the curb ring, which enabled lining to take place above the bottom of the shaft, and the use of multideck stages allowing sinking and lining to be carried out concurrently, resulted in a major advance in shaft-sinking techniques. As the shafts were deepened, larger buckets carrying more tonnage led to the development of multirope suspension, to four-drum stage hoists, and to Blair double-drum friction hoists. For greater control of a water zone, another improvement was grouting before shaft sinking commenced.

Leading the world in perfecting high-speed shaft sinking methods is the mining industry in South Africa, where the ever-increasing costs of deep mining led to developing new techniques. A comparative example of shaft-sinking records attained in South Africa shows how design, mechanization, and improved techniques accelerated the sinking rate: 585 feet were advanced in 1 month at the Vlakfontein mine in 1953 versus 1,261 feet attained in 1 month at the Buffelsfontein mine in 1961 (31, 79).

Although sometimes construction tunneling in soft rock is not thought to be comparable to tunneling for ore recovery, new developments in this area are leading to more adaptations in the hard-rock mining industry. Methods thus developed will be modified and adapted as the mining industry turns more to large-scale underground extraction of lower grade ores in order to meet national resource goals and to comply with environmental standards.

The larger tunneling machines employed by the construction industry usually have been assembled and initiated on the surface and used in a straight drive. Recently, companies have developed machines with more flexibility in

direction and shape of openings, design, and performance of cutting heads to allow the penetration of harder rock. The high cost of the machines has been a deterrent to experimentation in underground mining operations.

In 1969, the rapid excavation of tunnels by conventional methods (drilling, blasting, and loading) was at rates of 50 to 75 feet per day. An example of the rate of tunnel construction by conventional means was the driving of the San Francisco Bay Area Rapid Transit (BART) tunnels. Driven in about 20 months, May 1965 to March 1967, the horseshoe-shaped Berkeley Hills Twin Transit tunnels were both 21 feet in diameter and 16,232 feet long. The average driving rate for the "CL" tunnel was 18.6 feet per day; maximum driven in 24 hours was 60 feet. Average driving rate for the "CR" tunnel was 18.5 feet per day; maximum driven in a 24-hour period was 68 feet. Problems included caveins, squeezing ground in the Hayward and other fault zones, and water. Formations included siltstone, sandstone, conglomerates, and volcanics. Conclusions from this work were that careful supervison and cautious mining allowed the most rapid excavation (3). A record for conventional drill and blast tunneling was set with the 115 feet advanced in a single day, in the 15-foot-wide and 15-foot-high Granduc tunnel of Newmont Mining Corp. The tunnel was driven in the Portland Canal area, British Columbia, in the late 1960's (40, 56, 67).

Footage advanced per unit of time is a function of rock type and rock-strength characteristics, rock conditions, diameter of bore, type of machine, teamwork, and the capability of the supervisor.

In 1972, Fluor Utah Engineering & Construction, Inc., boring a 20.5-foot-diameter tunnel, advanced as much as 260 feet in a 24-hour day through sandstone and siltstone at the Navajo Tunnel No. 3, U.S. Bureau of Reclamation Navajo irrigation project near Farmington, N.M. (2). Factors contributing to this rapid rate of advance were rebuilding of cutters in the field, installation of rock bolts close to the face allowing drilling to continue throughout the cycle, and highly automated muckcar handling at the heading (21).

A record was established in 1966 at the Oso tunnel of the Bureau of Reclamation, San Juan-Chama project in south-central Colorado. The Robbins 104-121A model mole used in the 10-foot 2-inch-diameter tunnel made a maximum advance of 419 feet in one 24-hour day, 1,905 feet in one 6-day week, and 6,849 feet in one 26-day month through the Lewis Shale. The time required for the delivery of the mole to the tunnel site was 7 months (68).

Mechanical raise borers have been developed and used extensively. In 1971, a new record was established at the Cia Fresnillo S.A. Naica mine in Mexico: a 7-foot-diameter, 1,140-foot raise was completed in 13 days, with an average reaming advance of 11 feet per hour. High rock temperatures and water prevented driving the raise by conventional means (38).

Construction or development of the underground operation may utilize pre-existing workings, including those driven in the exploration phase or those driven specifically for the project, thus shortening the development period. Rehabilitation of an old mine may require dewatering the workings, retimbering

shafts and tunnels, repairing caved areas, and refurbishing with rail, ventilation pipe, machinery, and surface plant. The planned construction would incorporate old workings that may be used and proceed with developing the ore body.

For a completely new operation, shafts or tunnels driven for exploration will probably be used during the development period; these workings may be maintained later as a production or supply route. Newly discovered deposits amenable to underground mining require a longer time to develop than most open pit operations. A shortened construction period for underground mines will come with the development of (1) more efficient removal of rock cuttings during shaft sinking and tunneling, (2) automation techniques, (3) improved ventilation from the removal of blasting and diesel fumes to the removal of dust from the work area, (4) heat and water control, (5) more rapid installation of ground-control units--rock bolts, screens, grout, or concrete, (6) new or refined rock-fragmentation and disintegrating techniques, (7) mechanical boring machines better adapted for hard-rock mining, and (8) better teamwork and more experienced miners and supervisors.

Auxiliary support facilities will be constructed during the development of the mine. The sequence of events in the acquisition and construction of these facilities will vary with the operation. Water may have to be piped in from a considerable distance. Conversely, some mines will be faced with too much water; thus, the availability of pumps and a constant, unfailing supply of power become extremely important. A mining district with operating mines will have a developed transportation network; however, properties in newer districts will need access roads within the district and possibly roads or railroads to marketing outlets.

The construction of the mine and installation of surface facilities will continue to require an awareness of the environmental impact. Mining operators have always had to consider safe, effective mining techniques to prevent damage to men, the mine, and the environment, all influenced by the amount of money available for elaborate mine systems.

Underground mining methods do not always leave the surface undisturbed. Surface subsidence will occur if the stopes are not backfilled and properly supported by pillars, or if the stopes are intentionally caved to surface such as in the block-cave method.

Construction of Beneficiation Plant

Beneficiation is the processing of ores to regulate the size of the desired product, remove unwanted constituents, and improve the quality and grade of the wanted mineral.

In general, treatment of ores invloves several types of operations depending on the nature of the ore material. Beneficiation ordinarily requires reducing the size of the ore by crushing and grinding, sizing and classifying the material for further treatment, and recovering the valuable constituents. Included among the many processes which may be used are flotation of copper,

lead, and zinc sulfide ores; cyanidation of gold ores; heavy-media separation (sink-float process) for iron ores, coal, and gravel; magnetic separation of iron ore; and leaching and precipitation of copper and uranium ores.

The flotation process is the conventional method of concentrating the sulfide copper ores. Molybdenum, frequently occurring in porphyry deposits, is separated by selective flotation from the copper concentrate.

Construction of a beneficiation plant or concentrator must begin after ore reserves have been established, after a favorable feasibility study has been concluded, and after financial arrangements have been completed. For economic reasons, the initial size of the mill is usually restricted to the minimum for profitable operation. Based upon anticipated change in ore grade, plans allow for future expansion to the apparent optimum size.

Contributing to the time required to construct the concentrator and bring it into production are such factors as leadtime in acquiring the equipment, the tuneup period, and the location of the mill in relation to the mine. Among the items considered in locating the concentrator are transportation costs, topography to take advantage of gravity flow, adequate space for tailings-disposal area, availability of a sufficient and dependable supply of water and power, environmental hazards such as floods, landslides, and snowslides, and pollution control.

The routine flotation treatment of the sulfide porphyry copper ores is fairly well established; about 2 years is required for construction of the mill. The time required for expanding the concentrator will depend upon the size of the increase, any changes in the process, and whether allowances for the expansion were made during the design stage.

Once the initial construction of any mine or concentrator is completed, the economics of operation require flexibility in responding to changing conditions. Adaptation to new techniques requires alert management, careful planning, and willingness to experiment, as well as skillful timing to achieve increased production at the propitious moment.

This adaptability was demonstrated at the Miami mine, which grew from a 3,000- to a 17,000-tpd operation in four increments between 1911 and 1929. The early high-grade ores from this underground operation were treated in a gravity concentrator constructed and brought to capacity in about 3 years. Within 5 years, the plant had been converted from gravity to the then-new flotation process. As the high-grade ore reserves were depleted, the development of the high-column block-cave mining method allowed low-grade ores to be mined profitably. The average costs dropped $0.758 per ton in 2 years. During the 1930's depression, the company developed the leach-precipitation-float process which improved recovery of the mixed oxide-sulfide ores. To extract additional values from abandoned areas of the Miami mine, leaching, begun in 1941, has continued to the present, or over 33 years. These events and the development of the Miami East ore body illustrate how mine life has been extended by new mining and beneficiating techniques that allow increased tonnages and the recovery of low-grade ores.

Each expansion has its own leadtime, including periods for exploration feasibility studies, construction, and production.

Nonsulfide copper ores may be treated by leaching both at open pit and at underground operations. The leach process may be instituted at the commencement of the operation or later, supplementing the conventional flotation treatment of copper ore. In addition, the process often becomes a vehicle for extending the life of the mine by allowing the recovery of copper unattainable by other means of mining and treatment.

Diverse leaching methods include dump leaching of waste material, heap leaching of low-grade ores, vat leaching of high-grade amenable ores, and in place or in situ leaching of areas fractured by prior mining or coyote blasting. The copper is recovered from the leach liquors by precipitation on iron in the form of shredded cans, iron scrap, or sponge iron; less commonly, electrolysis of the vat-leach liquors or solvent extraction and electrolysis of the leach liquors are used for recovery. Precipitate or cement copper is shipped to the smelter for conversion to blister copper and then to the electrolytic plant. For many years the leach process was a catch-as-catch-can operation; however, the application of scientific research and development led to improved planning and engineering of open pit and underground mining, resulting in maximum recovery of copper through a combination of sophisticated leaching processes and flotation concentration processes.

Briefly, the dump leach method is as follows. Waste and/or low-grade material resulting from the mining of higher grade sulfide ore is placed on the most suitable existing topography--in some areas an impervious pad is necessary to prevent loss of leach solutions. The natural or treated mine or surface water is distributed over the area by various means including piping the solutions into ponds and trenches, or spraying the solution over the area in a gridlike pattern. The pregnant solutions that have percolated through the dumps are collected in a storage area and circulated through the precipitation plant, which consists of launders, vats, or tanks containing detinned cans or other scrap iron. Percolation of solutions through the dumps may require 3 days for a 250-foot dump and 12 days for a 500-foot dump (78). The waste dump at Mineral Park, Ariz., is estimated to contain over 5 million tons of material; at Bingham Canyon, Utah, the dumps contain some 4 billion tons.

Heap leaching is used to recover copper from a porous oxide copper ore that has been placed on a prepared impervious surface. The ore is generally higher grade material than that which is dump leached. A strong acid solution is often distributed over the material; the quantity of acid consumed is a function of the type of host rock and the copper minerals leached. Acid solution is distributed on a heap leach for 100 to 180 days, at which time the economically recoverable copper content has been leached. Copper in the pregnant solution may be recovered by precipitation, solvent extraction, and/or electrolytic deposition.

In vat leaching, the copper is extracted from mixed sulfide-oxide ores containing more than 0.5 percent acid-soluble copper. The ore is crushed and screened before treatment. Theoretically, a high recovery is accomplished

because the grinding treatment allows more contact with the copper minerals and because less of the pregnant liquor is retained in fines. Flow rates are affected by permeability of the ore bed, and higher temperatures produce an increase in the percolation rate.

Kennecott Copper Co. recently designed and constructed a new silicate vat leaching plant at Ray Mines division within a time span of over 3-1/2 years from initiation of the study to completion of the project in March 1969. Study and development of the new process to treat the ores commenced in mid-1965, and the pilot plant was completed in 6 months (by June 1966). As a result of a successful 4-month testing period, the leaching plant was built; ground preparation required 6 months and construction of the plant 22 months (66).

In place or in situ leaching of copper ores has been used for many years. The method involves much the same process as in dump and heap leaching; the solutions percolate through areas that have previously been mined (usually block caved) or coyote blasted and are then retrieved and precipitated by one of the methods previously mentioned.

Examples of mines that collected the leach solutions of previously mined areas are the Ohio Copper Co., Bingham, Utah, beginning about 1925 (now incorporated into the Utah Copper pit of Kennecott Copper Corp.); Ray mine of Kennecott, Ray, Ariz., beginning about 1938 (now using a vat-leach process); Miami mine, Miami, Ariz., beginning leaching in 1941 and continuing to the present (1972). At the Miami mine, the acid solution, sprayed over the surface of the caved area, percolates through 600 feet of material in 3 to 4 weeks and is then collected and pumped to the precipitation plant (60).

An example of the large-scale coyote blasting of a deposit is the Old Reliable deposit in the Copper Creek mining area, 9 miles from Mammoth, Ariz. Now leased by Ranchers Exploration and Development Co., the mine was operated by underground conventional methods from 1890 to 1919 and again in 1953-54. Ranchers acquired the property by lease in October 1970. In April 1971, roads were made for access to the property; preparation for blasting was begun with excavation of tunnels and crosscuts by September 1971; ammomium nitrate emplacement commenced in late January 1972; and the explosives were detonated March 9, 1972. The ore deposit is 400 feet in diameter and about 500 feet deep; the blast affected an area 450 to 500 feet in diameter. Terracing, begun March 15, 1972, was completed May 30, 1972. Benches were cut to allow the spraying of the sulfuric acid solution over the entire area; leaching began in August 1972. The precipitate plant, equipped with shredded cans to precipitate the copper, was completed and production was begun by late 1972, for a total period of about 2 years (77).

In the leaching process, factors influencing the amount and rate of recovery of copper include careful distribution of solution over the entire area to assure contact with the copper minerals, the process itself, the type and grade of ore, and the maintenance of the proper pH of the leach solutions. Problems are the channeling of solutions in dumps, heaps, mines, and even in vats; gelatinous iron-salt precipitation in the leach dumps that creates

impervious boundaries to the distribution of the solutions; loss of the leach and pregnant solutions by evaporation or permeable ground; corrosion of equipment by the acids; maintenance of low iron consumption and maximum copper precipitation; amount of water available; maintaining alternating wet and dry periods; and recycling solutions that have collected clays that act as a copper absorbent (60).

The construction period for the leaching plant will depend on the size of the operation, the process used, anticipated life of the facilities, location of the plant with respect to the mine and source of supplies, and availability of equipment, and whether it is custom designed or standard.

For the leach process, the time period begins with the fragmentation of dump and heap leach material during the mining phase. Fragmentation of in place leaching material may occur during the mining phase if the material is mined by a method resulting in major subsidence such as block caving. In situ leach material may also be fragmented by the large-scale use of explosives detonated within a deposit, such as at the Old Reliable mine where preparation for placement of explosives and detonation required almost 2 years. In the vat-leach process, the material is mechanically crushed before it is placed in the vats.

Leaching equipment for dump and heap leaching may be installed in only a few months. Development of a new process, such as the vat leach, or the elaboration of an old technique could entail years of testing; the custom manufacturing, installation, and use of newly designed equipment might require 2 years.

The duration of leach periods has been described as follows--dump leaching and in place leaching periods are measured in years, heap leaching is measured in months, and vat leaching is measured in days (60).

Environmental Protection and Reclamation

Environment has been defined as the summation of all the external conditions that may influence the development or existence of an organism or community. Ambient air, light, moisture, temperature, wind, soil, and all organisms are part of the environment or environmental factors. These factors may also include structures, whether natural or manmade objects, and social elements such as customs, laws, and language.

Additional leadtime in developing a mine may be required to determine and analyze the impact of the environment on the operation and the impact of the operation on the environment. A hostile environment, such as the Sonoran desert with its heat or glaciated mountain terrain at high altitude with difficult transport, decidedly affects the productivity of the work force and the efficiency of a mine complex. These elements, viewed as a part of the operating risks and costs, have always influenced the economic and technologic decisions of management and taxed corporate ability to adjust to the necessities of the environment.

Conversely, the effect of the mining operation on the environment, though given planning effort and attention in the past, was never considered in the degree now demanded of the industry. Reclamation of the mined-out area, the mine dumps, and the tailings disposal area were often of small concern, principally because the disturbance of the earth's surface was in remote areas and not of particularly large scale. With the development of strip coal mining and the increased mobility of people due to improved highway systems and air transportation, the scars on the earth's surface have become more apparent to more people. In recent years new State and Federal laws have been enacted, requiring that all future mining be "environmentally" controlled, from exploration through final reclamation.

Exploration time will be increased by the time required to gain approval from the specific State or Federal agency concerned. Depending on the location and the commodity, various permits and licenses are required from State agencies, and Federal approval will have to be obtained from the Forest Service or Bureau of Land Management. This time will vary with the location, with the commodity involved, and with the time needed to comply with the regulations. Requirements may specify that roads and drill sites have to be placed in inconspicuous areas; topsoil stockpiled for future use; trenches and pits refilled; sump areas provided to prevent slimes from the drill water entering the drainage; and abandoned sites covered and seeded.

At some time during the feasibility study the company planning a project may have to prepare a report for the various State and Federal agencies, indicating measures that will be undertaken to protect the environment.

In some States the leadtime for exploration and/or development of a surface mining project may be further lengthened by the requirement to obtain a permit and post bond with the State. If an Environmental Impact Statement (EIS) is needed, preparation time by the agency will be required; allowance may also have to be made for the statement to be reviewed by other concerned government agencies and by the general public.

In January 1972, Bureau of Land Management Regional Planner Kenneth F. Reinert estimated 90 weeks or 1-3/4 years would be required to implement a work proposal (41).

Land changes brought about by a mining and milling operation may include the open pit scars on the earth's surface and the formation of waste dumps. Underground mining may form areas subject to planned or unplanned, gradual or sudden subsidence. Installation of a tailings pond may block natural drainage in lowlands or canyons, or cause siltation downstream. Another problem associated with tailings disposal is that of controlling blowing sand and dust.

Reclamation of strip mine areas may proceed with or immediately after removal of material being mined. However, an open pit copper mine requires many years to remove the ore, and any reclaiming process applied to the pit must wait until mining is terminated. Even then the cost in time and money might well be prohibitive. For example, at an estimated cost of $7 billion,

the suggested backfilling and recontouring of the Utah Copper pit of Kennecott would require 66 years if filling proceeded at a rate of 400,000 tpd (17). Certain underground mining methods, such as open stopes and supported stopes, might allow filling by waste material or tailings as mining progresses, thereby shortening the reclamation period. Planning an aesthetic tailings disposal area at present commences during the mine-mill construction phase. The shape and location of the area are determined at this point; stabilization of tailings sand by use of vegetation and other means can begin at any time. The Twin Buttes mine, Pima mine, and Miami mine are noted for their use of grass, shrubs, and trees to improve the tailings area.

Although the reclamation of the mining area will ideally be considered at the beginning of the project, many open pit mines are of long duration. Hence, original planned reclamation of the area might be limited, reflecting only possible land use, because rapidly changing social and cultural values may evolve a totally new concept of reclamation between the initiation of the project and the cessation of mining some 10, 50, or 100 years later.

When any metal mine will conclude its operation is highly unpredictable. The cessation of operations within a mining district often does not mean that the resource has been exhausted. Rather, resumptions of operations may await higher prices for metals or the development of a new technology; therefore, efforts toward reclamation should be carefully considered so as not to render the mine prematurely inoperative.

As mining proceeds, control of the quality and quantity of water is a constant concern. The leadtime in bringing a mine into production is affected by extremes in either oversupply or undersupply. A classic illustration of this water-control problem and the environment within the mine was the difficulty in regulating the flow of water in the Fad shaft at Eureka, Nev. This rich sulfide ore body, discovered in the 1940's by Eureka Corp. Ltd. and the Bureau of Mines, has yet to come into production, because of excessive water inflows.

Conservation of mine water and maintenance of quality are evidenced by the recycling of water from leaching operations and from the concentrator effluents.

When the operation includes smelting and refining, environmental problems are compounded. The leadtime may be extended by the requirements of the new environmental pollution regulations. Sulfur dioxide emission is the principal pollutant in smelting copper, lead, and zinc sulfide ores; this waste product has yet to be sufficiently controlled to meet the Federal environmental standards set up in May 1970. Although variances were granted, existing smelters were ordered to achieve compliance to environmental regulations by 1975. The removal of SO_2 at existing plants requires additional scrubbers and electrostatic precipitators which, in 1973, required 2 years for fabrication and delivery from the date of purchase order, as all such apparatus has to be custom designed and constructed for the individual plant.

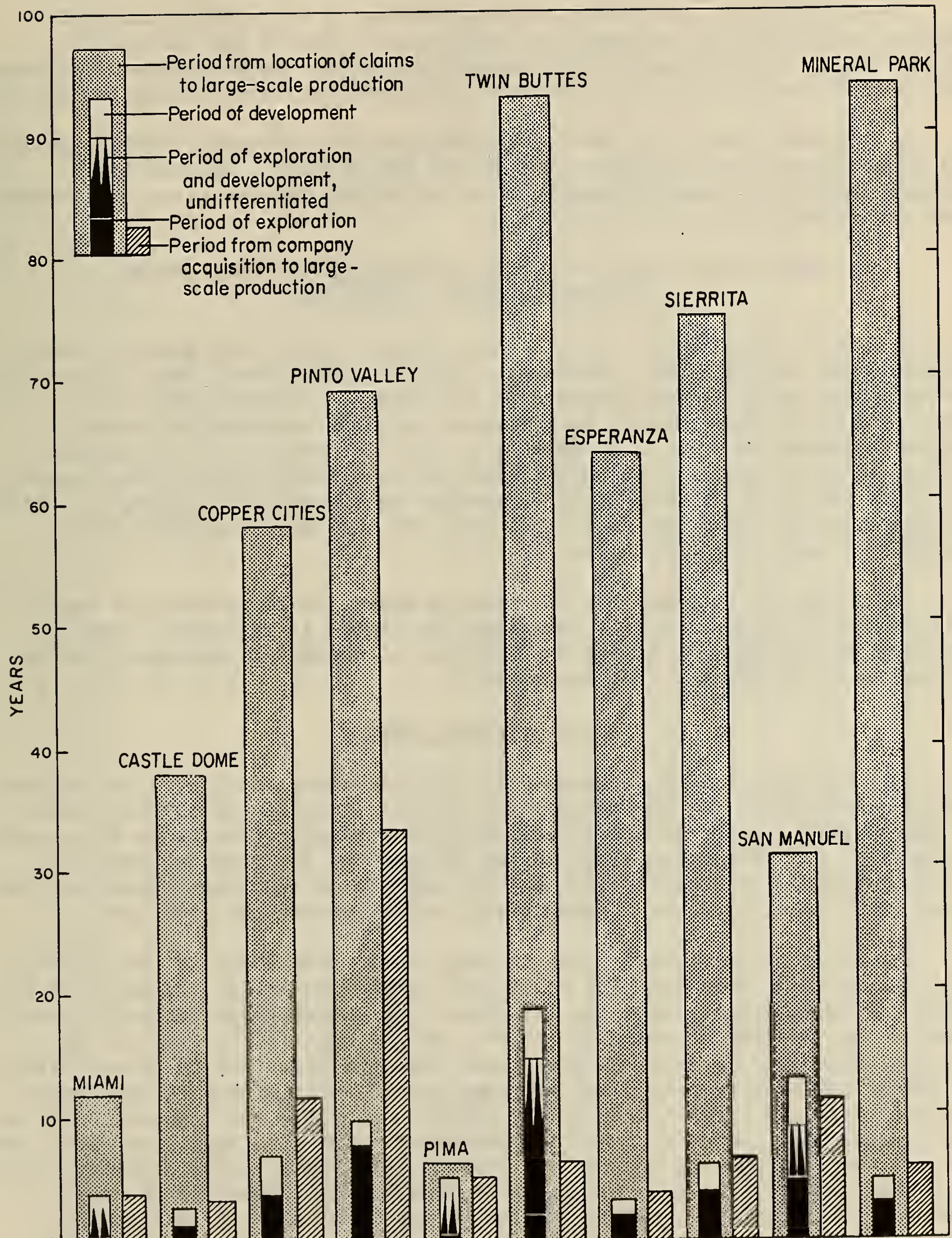

FIGURE 1. - Time periods for various phases of development at selected copper mines.

Installation of acid plants for the conversion of sulfur dioxide to sulfuric acid has been estimated to require 2 to 3 years for the modern smelter and possibly longer for older smelters (75). Construction of sulfuric acid plants has been delayed, principally by problems in marketing the acid.

All of the major copper smelting companies are diligently doing research and examining new technology to resolve the SO_2 problem. Many of these research techniques involve chemical extraction and modifications or abandonment of pyrometallurgical procedures.

TIME REQUIREMENTS FOR SPECIFIC EVENTS IN THE DEVELOPMENT OF SELECTED COPPER PROPERTIES

Histories of the Miami, Castle Dome, Copper Cities, San Manuel, Twin Buttes, Pinto Valley, Pima, Esperanza, Sierrita, and Mineral Park properties document the growth and development of the large-scale operation. Data on these properties were studied to determine the time required to perform various segments of work. In addition to the discussions in this section records of development of the Miami, Castle Dome, Copper Cities, San Manuel, and Twin Buttes are chronologically detailed in appendixes A through E. Each of these records functions as a study unit and includes a specific bibliography for that particular mine.

The estimated time periods for various phases of development at the selected copper properties are summarized in figure 1 and table 1, and detailed in tables 2, 3, 4, and 5. Grouping of these data provides a means of comparing the related time intervals.

Time Periods Defined

From the information documented in the literature, estimates of the following time periods for the mines were studied: Location of initial claims to large-scale production; acquisition by the producing company to large-scale production; preliminary examination and evaluation; exploration; mine and beneficiation-plant construction; and the periods of expansion, plus leaching of marginal ores to increase productivity and to extend the mine life.

The location of mining claims to large-scale production is the interval from the initial claim location to the date when substantial shipments of ore began. In most cases, the dates illustrate the considerable number of years between the time the claims were located and the onset of large-scale production. The various mine histories show that the mines are in or near areas of known mineralization and that prospecting and early mining of high-grade deposits were not sufficiently remunerative to keep the mines operating without numerous shutdowns or complete abandonment. The time span, therefore, may include many prospecting periods and intermittent small-scale production. For the mines studied, the interpretation of large-scale production changed dramatically from the 3,000 tpd treated at the Miami mine in 1911 to the 72,000 tpd treated at the Sierrita mine in 1970.

TABLE 1. - Historical synopsis of selected copper mines through 1972

Mine	Location of claims to large-scale production: Date	Period	Company acquisition to large-scale production: Date	Period	Preliminary examination and evaluation: Date	Period	Major exploration: Date	Period	Development: Date	Period	Beneficiation plant construction: Date	Period	Capacity, tpd	Break-in period	Beneficiation plant expansion: Date	Period	Total designed capacity, tpd	Leaching period: Starting date	Period	Mine operating period
GLOBE MIAMI DISTRICT, 1873-1911 (CA. 38 YEARS)																				
Miami[1]	Ca. 1899-Mar. 1911	Ca. 12 yr	Late 1906-Mar. 1911 (Miami Copper Co.)	Ca. 4 yr 3 mo	Jan. 1907-June 1907 (Miami Copper Co.)	6 mo	1907-10 (Underground and surface, Miami Copper Co.)	3 yr	Apr. 1907-Mar. 1911 (Underground, Miami Copper Co.)	3 yr 11 mo	Apr. 1909 Mar. 1911	1 yr 11 mo	3,000	11 mo	1913-18 1923-25 1927-28 Dec. 1928-Oct. 1929	5 yr 2 yr 1 yr 10 mo	6,000 10,000 12,000 17,000	1942	31 yr to date	48 yr 4 mo
Castle Dome	Ca. 1905-June 1943	Ca. 38 yr	Fall 1940-June 1943 (Miami Copper Co.)	Ca. 2 yr 9 mo	Fall 1940-End 1941 (Miami Copper Co.)	Ca. 1 yr	Fall 1940-End 1941 (Surface, Miami Copper Co.)	Ca. 1 yr	Jan. 1942-June 1943 (Open pit, Miami Copper Co.)	1 yr 5 mo	Jan. 1942-June 1943	1 yr 5 mo	10,000	6 mo	Dec. 1943-Late 1944	Ca. 1 yr	12,000	1953-70	18 yr	10 yr 6 mo
Copper Cities	Ca. 1896-Aug. 1954	Ca. 58 yr	1942-Aug. 1954 (Miami Copper Co.)	Ca. 12 yr	([2])	([2])	1943, 1946-49 (Surface, Miami Copper Co.)	Ca. 4 yr	June 1951-Aug. 1954 (Open pit, Miami Copper Co.)	3 yr 2 mo	Dec. 1953-Aug. 1954	8 mo[3]	12,000	3 mo	None reported	None reported	12,000	1962	11 yr to date	18 yr 4 mo to date
Pinto Valley[4]	Ca. 1905-(1974)	(49 yr)	1940-(1974) (Miami Copper Co.)	(34 yr)	-	-	1961-69 (Surface?--Cities Service Co.)	8 yr	Aug. 1972-(1974) (Open pit, Cities Service Co.)	(2 yr)	1972-(1974)	(2 yr)	(40,000)	-	-	-	-	-	-	-
Miami East[5]	-	-	Not reported	-	1923-25 (Miami Copper Co.)	2 yr	Aug. 1969-1972? (Underground, Cities Service Co.)	2 yr?	-	-	-	-	-	-	-	-	-	-	-	-
PIMA MINING DISTRICT, 1875-1956 (CA. 81 YEARS)																				
Pima	July 1950-End 1954	6 yr 5 mo	Nov. 1951-Dec. 1956 (Pima Mining Co.)	5 yr 1 mo	Late 1949-July 1950 (United Geophysical Co.)	Ca. 9 mo	Feb. 1951-Dec.? 1951 (Surface, United Geophysical Co.)	10 mo?	May 1952-Oct. 1955 (Underground, Pima Mining Co.)	3 yr 5 mo	-	-	-	-	-	-	-	-	-	-
			Aug. 1954-Dec. 1956 (Cyprus Mines Corp.)	2 yr 4 mo	Aug. 1954-Aug. 1955 (Cyprus Mines Corp.)	1 yr	Jan. 1952-May? 1952 (Underground, Pima Mining Co.)	5 mo?	Nov. 1955-Dec. 1956 (Open pit, Cyprus Mines Corp.)	1 yr 1 mo	Dec. 1955-Dec. 1956	1 yr	3,000	NA	1962-Aug. 1963 Dec. 1964-July 1966 Sept. 1966-July 1967 Fall 1970-Feb. 1972	Ca. 1 yr 1 yr 7 mo 10 mo Ca. 1 yr 6 mo	6,000 18,000 30,000 53,000	None reported	None reported	16 yr to date
Twin Buttes	Ca. 1876-1969	Ca. 93 yr	-	-	-	-	1950-63 (Underground and surface, Banner Mining Co.)	13 yr	-	-	-	-	-	-	-	-	-	-	-	-
			Mar. 1963-Sept. 1969 (The Anaconda Co.)	6 yr 6 mo	Mar. 1963-Apr. 1964 (The Anaconda Co.)	Ca. 1 yr	Mar. 1963-Mar. 1965 (Surface and underground, The Anaconda Co.)	2 yr	July 1965-Sept. 1969 (Open pit, The Anaconda Co.)	4 yr 2 mo	Aug. 1967-Sept. 1969	2 yr 1 mo	30,000	7 mo	Planned 1971	NA	32,000	None reported	None reported	3 yr 3 mo to date
Esperanza	1895-1959	64 yr	Feb. 1955-Mar. 1959 (Duval Corp.)	4 yr 1 mo	Late summer, 1954 (Duval Corp.)	Ca. 2 mo	May 1955-June 1957 (Surface and underground, Duval Corp.)	2 yr 1 mo	Nov. 1957-Mar. 1959 (Open pit, Duval Corp.)	1 yr 4 mo	July 1957-Mar. 1959	1 yr 8 mo	12,000	9 mo	Completed June 1967	NA	15,000	1962	11 yr to date	12 yr 9 mo to 1971[6]
West Esperanza	-	-	-	-	-	-	July 1960-1962 (Surface, Duval Corp.)	Ca. 1 yr 6 mo	Mar. 1963-Aug. 1965 (Open pit, Duval Corp.)	2 yr 5 mo	-	-	-	-	-	-	-	-	-	-
Sierrita	Ca. 1895-1970	Ca. 75 yr	-	-	-	-	1960-1963? (Surface, Bear Creek Mining Co.)	3 yr?	-	-	-	-	-	-	-	-	-	-	-	-
			Late 1963-Mar. 1970 (Duval Corp.)	Ca. 6 yr 3 mo	Late 1963-July 1964 (Duval Corp.	Ca. 7 mo	Late 1963-1964? (Surface and underground, Duval Corp.)	1 yr?	Feb. 1968-Mar. 1970 (Open pit, Duval Corp.)	2 yr 1 mo	Feb. 1968-Mar. 1970	2 yr 1 mo	72,000	1 yr 2 mo	Aug. 1970-Jan. 1972	1 yr 5 mo	85,000	None reported	None reported	2 yr 9 mo to date
OLD HAT DISTRICT, 1879-1956 (77 YEARS)																				
San Manuel	1925-56	31 yr	Aug. 1944-Jan. 1954 (Magma Copper Co.)	11 yr 4 mo	Aug. 1944-Sept. 1965 (Magma Copper Co.)	Ca. 1 yr	Dec. 1944-Feb. 1948 (Surface,[7] Magma Copper Co.)	3 yr 2 mo	Jan.-1953-Jan. 1956 (Underground, Magma Copper Co.)	3 yr	Ca. July 1953-Oct. 1955	Ca. 2 yr 3 mo	30,000	NA	Jan. 1964-July 1965 Spring 1969-Nov. 1971	1 yr 7 mo Ca. 2 yr 9 mo	40,000 60,000	None reported -	None reported -	16 yr 11 mo to date -
							Mar. 1948-Ca. July 1952 (Underground, Magma Copper Co.)	4 yr 4 mo	-	-	-	-	-	-	-	-	-	-	-	-
Kalamazoo[4]	1946-(1980)	(34 yr)	-	-	-	-	1965-67 (Surface, Quintana Minerals Ltd.)	Ca. 2 yr	-	-	-	-	-	-	-	-	-	-	-	-
			Mar. 1968-(1980) (Magma Copper Co.)	(12 yr)	-	-	-	-	Nov. 1968-(1980) (Underground, Magma Copper Co.)	(12 yr)	-	-	-	-	-	-	-	-	-	-
WALLAPAI DISTRICT, 1870-1964 (94 YEARS)																				
Mineral Park	1870-1964	94 yr	Dec. 1958-Oct. 1964 (Duval Corp.)	6 yr	Oct. 1958 (Duval Corp.)	1 mo?	Mar. 1959-Ca. June 1962 (Surface and underground, Duval Corp.)	Ca. 3 yr 3 mo	Jan. 1963-Oct. 1964 (Open pit, Duval Corp.)	1 yr 9 mo	Mar. 1963-Oct. 1964	1 yr 7 mo	12,000	4 mo	NA	NA	17,000	1965	8 yr to date	8 yr 2 mo to date

NA--Not available.
[1] The exploration period also included some surface exploration as early as 1909. Underground mining was discontinued in mid-1959; leaching of mined-out areas was continued to date (1972).
[2] Bought at sheriff's sale.
[3] Mill moved from Castle Dome to Copper Cities and reassembled.
[4] Projected data are given in parentheses.
[5] Incomplete.
[6] Temporarily closed.
[7] This exploration period does not include the preliminary work done by the Bureau of Mines and the Geological Survey from March 1943 to February 1945, 1 yr 11 mo.

Source: Company annual reports and other published literature.

TABLE 2. - Exploration period

District and property	Type of exploration operation	Time period	Total time	
			Years	Months
Globe-Miami district:				
Miami	Underground and surface[1]	1907-1910	3	-
Castle Dome	Surface[2]	Fall 1940-end 1941	~1	-
Copper Cities	.....do[2]	1943, 1946-49	~4	-
Pinto Valley	Surface	1961-69	8	-
Miami East	Underground	August 1969-1972?	2?	-
Pima district:				
Pima:				
United Geophysical	Surface[2]	February 1951-December 1951?	-	10?
Pima Mining Co	Underground[1]	January 1952-May 1952?	-	5?
Twin Buttes:				
Banner Mining Co	.....do[1]	1950-63	13	-
Anaconda Co	Surface and underground[1]	March 1963-March 1965	2	-
Esperanza	.....do[1]	May 1955-June 1957	2	1
West Esperanza	Surface[1]	Ca. July 1960-1962	~1	6
Sierrita:				
Bear Creek Mining Co	Surface[2]	1960-63?	3?	-
Duval Corp	Surface and underground[1]	Late 1963-1964?	1?	-
Old Hat district:				
San Manuel	Surface[2]	March 1943-February 1948	4	11
Do	Underground[1]	March 1948-Ca. July 1952	4	4
Kalamazoo	Surface[2]	1965-67	~2	-
Do	Underground[1]	NA	NA	-
Wallapai district:				
Mineral Park	Surface and underground[1]	March 1959-June 1962	~3	3

NA--Not available.
[1]Exploration and development.
[2]Exploration.

TABLE 3. - Mine development period

District and property	Type of operation	Thickness of overburden, feet	Initial rate of ore production, tpd	Mine development date	Mine development period		Amount of overburden initially stripped, million tons
					Years	Months	
Globe-Miami district:							
Miami Copper	Underground[1]	245- 500	3,000	April 1907-March 1911.	3	11	NAp
Castle Dome	Open pit	NA	10,000	January 1942-June 1943.	1	5	14
Copper Cities	...do	20- 120	12,000	June 1951-August 1954.	3	2	14
Pinto Valley[2]	...do	500	40,000	July 1972-November 1974.	2	4	60
Pima district:							
Pima	Underground[3]	200- 300	NA	May 1952-October 1955.	3	5	NAp
Do	Open pit	NA	3,000	November 1955-December 1956.	1	1	19
Twin Buttes	...do	400- 600	28,000	July 1965-September 1969.	4	2	246
Esperanza	...do	95- 100	12,000	November 1957-March 1959.	1	4	6
West Esperanza	Open pit[4]	NA	NA	March 1963-August 1965.	2	5	6
Sierrita	...do	50- 300	72,000	February 1968-March 1970.	2	1	121
Old Hat district:							
San Manuel	Underground[5]	0-1,900 (av 670)	30,000	January 1953-January 1956.	3	-	NAp
Kalamazoo[2]	Underground	2,500	NA	November 1968-1980(scheduled).	~12	-	NAp
Wallapai district:							
Mineral Park	Open pit	50- 150	12,000	January 1963-October 1964.	1	9	18

NA--Not available.
NAp--Not applicable.
[1]Square set, shrinkage stope, top slicing and later block cave mining methods.
[2]Expected rate of production.
[3]Underground method was largely experimental--not entirely successful.
[4]Expansion of the Esperanza pit.
[5]Block cave.

TABLE 4. - Beneficiation plant construction

District and property	Type of operation	Initial capacity, tpd	Construction dates	Construction period[1]		Break-in completion date	Additional time, months
				Years	Months		
Globe-Miami district:							
Miami Copper[2]	Gravity concentration (tables), copper.	3,000	April 1909-March 1911.	1	11	February 1912	11
Castle Dome[3]	Flotation, copper	10,000	January 1942-June 1943.	1	5	December 1943	6
Copper Cities	do	12,000	December 1953-August 1954.	-	8	November 1954	3
Pinto Valley	Flotation, copper-molybdenum.	40,000	July 1972-November 1974.	2	4	NA	NA
Pima district:							
Pima	Flotation, copper	3,000	December 1955-December 1956.	1	-	NA	NA
Twin Buttes	Flotation, copper-molybdenum.	30,000	August 1967-September 1969.	2	1	April 1970	7
Esperanza	do	12,000	July 1957-March 1959.	1	8	December 1959	9
Sierrita	do	72,000	February 1968-March 1970.	2	1	May 1970	14
Old Hat district:							
San Manuel	do	30,000	Ca. July 1953-October 1955.	~2	3	NA	NA
Wallapai district:							
Mineral Park	do	12,000	March 1963-October 1964.	1	7	February 1965	4

NA--Not available.
[1]Construction time extends to date first units went into operation. Molybdenum recovery section or plant often brought into operation at a later date: Miami Copper plant, August 1938; Pima, late 1967; Twin Buttes, May 1970; San Manuel, April 1956; Esperanza, May 1959; and Copper Cities, 1967.
[2]Miami mill converted to flotation by 1918.
[3]Mill from Castle Dome dismantled and moved to Copper Cities' property.

TABLE 5. - Expansion of selected beneficiation plants[1]

District and property	Initial designed capacity, tpd	Expansion, tpd	Total designed capacity, tpd	Expansion dates	Total time: Years	Total time: Months
Globe-Miami district:						
Miami Copper	3,000	3,000	6,000	1913-18	5	-
		4,000	10,000	1923-25	2	-
		2,000	12,000	1927-28	1	-
		5,000	17,000	December 1928-October 1929	-	10
Castle Dome	10,000	2,000	12,000	December 1943-late 1944	~1	-
Pima district:						
Pima	3,000	3,000	6,000	1962-August 1963	~1	-
		12,000	18,000	December 1964-July 1966	1	7
		12,000	30,000	September 1966-July 1967	-	10
		23,000	53,000	Fall 1970-February 1972	~1	6
Twin Buttes[2]	30,000	2,000	32,000	1971 (planned)		
Esperanza	12,000	3,000	15,000	Completed June 1967	NA	NA
Sierrita	72,000	13,000	85,000	August 1970-January 1972	1	5
Old Hat district:						
San Manuel	30,000	7,000	40,000	January 1964-July 1965	1	7
		20,000	60,000	Spring 1969-November 1971	~2	9
Wallapai district:						
Mineral Park	12,000	5,000	17,000	NA	NA	NA

NA--Not available.

[1]Concentrator often exceeded planned capacity owing to improved efficiency.

[2]Actual capacity apparently reached only 28,000 tpd. Expansion announced from 28,000 to 32,000 tpd, 1972.

In this study, company acquisition to large-scale production is the time span estimated to bring the property into initial large-scale production, after control has been obtained by location, option, lease, or purchase.

The preliminary examination and evaluation period is identified as the time the company has the property under option for purchase or lease, or simply as the time allotted for a brief examination of the property. Although the option periods are usually noted in the literature, information on the exact time required for the examination is less often stated.

Exploration may be divided into prospecting, or preliminary exploration, and detailed exploration periods. Detailed exploration delineates the ore body and ordinarily follows some form of preliminary examination and evaluation or feasibility study. Part of the exploration stage may be incorporated within the evaluation or option period.

Identification of the exploration time interval is difficult because available information does not always indicate when exploration begins and ends, nor when development starts. This condition is particularly true for underground mining, when initial exploration may include construction of a shaft or shafts used later for development and production.

Development or construction usually begins after the existence of a sufficient quantity of ore has been delineated. The construction period for an open pit mine commences when removal of the overburden begins and continues to the startup of the concentrator (mill). For the underground mine, the period is approximated by using the date ore was encountered underground or the date the author cites as the beginning of mine development. In the literature, the date underground exploration ceases and development begins is often not accurately defined; moreover, the authors may interchange the words "exploration" and "development" without regard to any technical definition.

The beneficiation plant construction period begins with site preparation and extends to the time the concentrator treats the ore on a continuing basis. After the concentrator has been built there is a break-in period when the plant is operated to determine whether the process and equipment will perform properly.

The time required to construct a concentrator or mill appears to be the most consistent and, perhaps, the most predictable interval in the preproduction period. The least known variable would be the design phase of the plant when the new process is under development, before the actual construction of the plant. The design phase is difficult to determine because an exact date is seldom announced when a company undertakes such a feasibility study; however, once the process has been successfully tested in a pilot plant, the construction of the full-scale plant appears to be routine.

Expansions of concentrators demand at least a commensurate increase in ore shipments from the mine and often a considerable investment in additional equipment and/or new buildings. Because design-capacity figures released by the companies are not always consistent, they may not reflect increases in

production that result from a more efficient operation rather than from a planned enlargment of the plant. Current large-scale production is often the result of several such periods of expansion.

Leaching of submarginal copper ores has been used for many years to recover copper values which might otherwise never be retrieved from mined-out areas and from waste dumps. This paper notes the length of time the process has been employed at the mines studied.

Descriptions of Selected Copper Properties

Miami Property (23, 37, 43-44, 51, 55, 70)

The Miami mine is in T 1 N, R 14 E, in the western part of the Globe-Miami mining district, near the town of Miami, Gila County, Ariz. The topography is fairly rugged, ranging in altitude from 3,300 feet in the Miami Wash to 4,000 feet along Inspiration Ridge. The climate is semiarid.

Miami Copper Co. owned the mine from its inception in 1907 until 1960 when the operation was acquired by Tennessee Corp. In 1963, Tennessee Corp. became a subsidiary of Cities Service Co.

The Miami-Inspiration deposit includes the Live Oak, Keystone, and Inspiration ore bodies mined by Inspiration Consolidated Copper Co. and the Pinto, Captain, and main ore bodies (including the Northwest and Southeast). The entire deposit is about 12,000 feet long and 2,500 feet wide. The Inspiration ore body is presently mined by open pit methods; the Miami ore body was mined by blockcaving methods from 1907 to 1959, overlappling with in situ leaching which began in 1942 and has continued to date (1972). The Miami ore body is described as irregular but roughly triangular with an altitude of 2,500 feet, a base of 3,700 feet in plan, and a thickness of about 350 feet. The Captain ore body was about 500 by 500 feet and averaged 350 feet in thickness; the Pinto ore body was 700 feet long and 300 feet wide.

The Miami ore body, a disseminated copper, is found in the Precambrian Pinal schist and, to a lesser extent, in the porphyritic border facies of the Tertiary Schultze granite stock. Capping, mainly consisting of a leached schist or granite porphyry, ranges from 245 to 500 feet in thickness; however, on the southeast side of the mined area as much as 150 feet of Gila Conglomerate covered the ore body. The thickness of the capping and the size and grade of the ore deposit were important in determining the mining method.

The principal ore mineral is chalcocite, with smaller amounts of chalcopyrite, bornite, covellite, malachite, azurite, chrysocolla, cuprite, native copper, and molybdenite. These minerals are in seams, veinlets, and disseminated particles. Much of the pyrite has been replaced with chalcocite, leaving only minor amounts of pyrite in the ore body. Secondary enrichment, very important in the formation of this deposit, has gone further to completion than in most mines in the Southwest.

Early prospecting in the Globe-Miami district was for gold and silver; then in 1881 copper became an important commodity. In the 1880's and 1890's, copper ores near the Miami area were mined from the Black Copper group, the Continental, the Keystone, and the Live Oak claims. At the turn of the century, John B. "Black Jack" Newman staked the claims that later became the nucleus of the Miami mine. These claims were optioned December 1906 by General Development Co., controlled by the Lewisohn interests of New York City. Exploration commenced in January 1907 with the start of sinking the first shaft, but no ore was found in this shaft; by April, ore had been found in the second shaft at a depth of 220 feet. In June, General Development Co. made the first payment on the option. The Miami Copper Co. was organized November 30, 1907, with General Development Co. holding 50 percent of the stock.

Lasting about 3 years, the exploration period at the Miami mine included the development period, which might technically be said to have commenced with the discovery of ore in the shaft 3 months after the start of exploration. This initial large-scale operation started production at 3,000 tpd in March 1911, about 12 years after the original claims were located and slightly over 4 years after the company acquired the property.

The Miami was operated as an underground mine for 48 years and as an in situ leach operation for 31 years; the latter has continued to the present (1972). Production is detailed in table A-1 in appendix A and the history of the property is summarized in table 6.

Examination of the production record, the reserves, the available cost records, and the historical record shows the mining and treatment of the early high-grade ores, their gradual decline in grade by 1925, and the recovery of copper from large quantities of low-grade ore from 1925 to 1959. The development of advanced techniques allowed the economical recovery of lower grade material considered as protores in the early days. Listed in historical order, these factors were--

1. Conversion of the original gravity mill to a flotation concentration process.

2. Development of block-cave method to mine the low-grade ores.

3. The development of the leach-precipitation-flotation (LPF) process to handle the oxide-sulfide ores.

4. Use of the leaching process to recover additional copper not economically feasible by other methods.

The original gravity mill was brought on stream in 1 year and 11 months; however, the break-in period lasted another 11 months before the 3,000-tpd designed capacity was achieved. The following year, installation of an experimental flotation cell marked the beginning of a changeover from a gravity-treatment process to a flotation process. This gradual conversion to flotation was completed in about 5-1/2 years; the capacity was increased to 6,000 tpd. High-grade mixed oxide and sulfide ore reserves were becoming depleted by 1923,

the development of the high-column block-cave mining method allowed low-grade material to be recovered economically. Within 6 years and 10 months, beginning in 1923, the mill capacity was increased from 6,000 tpd to 17,000 tpd.

Improvement in the recovery of mixed oxide and sulfide ores was achieved with the LPF process developed by the company during the Depression. The development required 5 years, including the 6 months necessary to construct a 3,000-tpd mill. The mixed-ore LPF plant treated 9.6 million tons of ore averaging 1.4 percent copper from 1936 to 1943, when the ore body was mined out and the plant dismantled.

From 1911 to 1925, sequential mining methods used to obtain the high-grade ore included top-slicing about 4.5 million tons after mining the peaks by square setting, shrinkage stoping with sublevel caving of pillars about 2.2 million tons, and, later, undercut caving with hand tramming about 15.4 million tons. Beginning in 1925, in order to mine low-grade ores, Miami developed a high-column method of block caving which dramatically reduced mining costs from $1.129 in 1924 to $0.371 per ton in 1926. Substantially the same block-caving method was used to mine 130.9 million tons from 1925 to 1959, when the underground operation was terminated.

Equipment for inplace leaching of abandoned areas of the mine was installed in 1941 to extract any copper remaining in the mined-out areas. This process has continued to the present (1972).

The greatest amount of ore from the underground mine treated in any 1 year was 6.1 million tons in 1930; the largest annual production of copper was about 72.9 million pounds recovered from the 4.87 million tons of ore treated in 1939. The maximum amount of copper from the leaching operations, 19.1 million pounds, was recovered in 1961, the second year after the underground operation was entirely converted to leaching.

The surface area disturbed by subsidence caused by the underground high-column block-cave-mining method was 3,400 feet north-south, about 2,600 feet east-west, and in some places over 400 feet deep.

The time period from the location of the first claims to full production at the Miami property of 3,000 tpd was about 12 years; the period to maximum large-scale production of 17,000 tpd was about 30 years. Table 10 contains a summary history of the Miami property; a detailed history is contained in appendix A.

The Miami Copper Co. grew with the acquisition of the Castle Dome, Copper Cities, Old Dominion, and Pinto Valley properties; these properties were later developed, resulting in the Castle Dome, Copper Cities, and Pinto Valley open pit mines. Because of local or world conditions, the properties were held by the parent company until it was economically feasible or desirable to bring them into production. Castle Dome was held 2-1/2 years, Copper Cities 12 years, and Pinto Valley 34 years. In addition to other sources, Old Dominion mine in the Globe area provided water for the other operations. To date,

however, the famous old mine has not been commercially exploited since its purchase in 1942.

The Korean conflict stimulated copper production, and in February Miami Copper Co. signed a contract with the Defense Minerals Procurement Agency whereby new copper production was obtained from submarginal ores and from old ore reserves of the Miami mine. The gross transactions by the Government eventually covered the actual purchase of 25,198 short tons of copper at $15,036,000 (including accessorial costs).

Another mineralized area, the Miami East deposit, is being brought into production. This deposit, a down-faulted segment of the Miami ore body, was first explored by underground drilling in the old Miami mine, 1923 to 1925. It was explored from the surface in 1940, and again from the surface from 1968 to 1970. The decision to develop the deposit was made in 1970; production is expected by late 1974. Fifty-one years will have elapsed from the year of initial exploration to expected production.

Contributing factors to the delay in the development of Miami East were probably the depth to the deposit, 2,500 feet, and the need for using underground mining methods, the price and demand for copper on the world market, and the adequate supply of ore to company processing facilities from existing operations.

TABLE 6. - Summary of the history of Miami property

Activity	Date	Total time period	
		Years	Months
Location of 1st claim in Globe-Miami district to initial large-scale production of Miami mine.	Sept. 19, 1873-March 1911.	37	6
Location of original claims to date of initial production from Miami mine.	Ca. 1899-March 1911	~12	-
Early prospecting, exploration, and production in Miami area to date of initial production from Miami mine.	1880's-1911........	~31	-
Acquisition by precursor of Miami Copper Co. to initial large-scale production (3,000 tpd).	Late 1906-March 1911.	4	~3
Option period, Miami Copper Co.............	January 1907-June 1907.	-	6
Exploration period, Miami Copper Co. (underground exploration and development, churn drilling adjacent to underground workings).	1907-10............	3	-
Mine development: Underground discovery of ore to initial large-scale production.	April 1907-March 1911.	3	11
Concentrator construction to initial large-scale production (design capacity: 3,000 tpd).	April 1909-March 1911.	1	11
Expansion:			
To 6,000 tpd............................	1913-18............	~5	-
To 10,000 tpd...........................	1923-25............	2	-
To 12,000 tpd...........................	1927-28............	1	-
To 17,000 tpd...........................	December 1928-October 1929.	-	10
Underground-mine period.....................	March 1911-July 1959.	48	4
Leaching period to 1972 (includes ownership by Tennessee Corp. 1959, and Cities Service Co. 1964 to date).	1942-72............	31	-

Castle Dome Property (37, 44, 51-52)

The Castle Dome area is 5 miles west of Miami in the Globe-Miami mining district, Gila County, Ariz. The mine is on the south flank of Porphyry Mountain in unsurveyed secs 20, 21, 28, and 29, T 1 N, R 14 E. The topography is fairly rugged and irregular. Altitudes at the open pit mine in 1951 were 4,750 feet on the top bench near the crest of Porphyry Mountain and 4,265 on the lowermost bench. The climate is semiarid.

The Castle Dome mine was brought into production by Miami Copper Co. in 1943. The open pit was operated until 1953; afterwards dump leaching was done

through 1970. In 1960, Miami Copper Co. merged with Tennessee Corp. which became a subsidiary of Cities Service Co. in 1963.

The Continental claim, some 3,000 feet northeast of Porphyry Mountain, was the first staked in the vicinity of the Castle Dome mine. The claim, located about 1881, was followed by other locations on nearby Jewell Hill and along Gold Gulch. From 1905 to 1910, many claims were located on Porphyry Mountain and on Pinto Creek, 2 miles to the south. The record of activity at Pinto Creek in the Cactus-Carlota area is more complete than in the Castle Dome area; however, some of the companies active in the Pinto Creek area eventually formed the nucleus of the Pinto Valley Co., which held the Castle Dome property at the time it was acquired by Miami Copper Co.

Capitalization and amount of holdings of various mining companies active during this early period are chronologically noted in appendix B. This sequence illustrates some of the financial problems in the attempts made to develop mines in the Pinto Creek and Castle Dome areas.

The Castle Dome Copper Co. organized in 1908 held 12 claims "near the Continental mine"; by 1909, the company was reorganized as the Castle Dome Mining Co. The property was idle in 1910. In 1915, the Castle Dome Development Co. was organized and held 8 patented claims on Porphyry Mountain and a 97-percent interest in Inspiration Extension Copper Co. which also held 20 patented claims on Porphyry Mountain. By 1922, exploration by the Castle Dome Development Co. included some seven churn-drill holes, eight tunnels, and 4,500 feet of workings to depths of 600 feet; the company reportedly developed a reserve of 10 million tons of ore averaging 1.4 percent copper.

Pinto Valley Co. was organized in 1921 to reassemble the properties of Arizona National Copper Co. and Cactus Development Co. which had attempted to operate in the Pinto Creek area. The Pinto Valley Co. then increased capitalization in 1924 and acquired the assets of Castle Dome Development Co. The 37 claims held on Porphyry Mountain became known as the Castle Dome group; those on Pinto Creek were known as the Cactus group. By 1929, Castle Dome reserves were estimated to be 9 million tons of ore containing 1.27 percent copper and 40 million tons of ore containing 0.8 percent copper. At that time plans were made to use block-caving mining methods similar to those used at the Miami and Inspiration mines and to have the ore treated by Inspiration Consolidated Copper Co. During the Depression, which saw the price of copper dip as low at 4.8 cents per pound, the company was unable to bring these plans to fruition.

According to the annual reports, an acute shortage of water for the Miami operation led to the purchase of the Old Dominion mine near Globe by Miami Copper Co. in May 1940. The negotiations included the Continental mine properties held by the Old Dominion since 1899; part of these properties covered the east end of the Castle Dome ore body. In the fall of 1940, Miami Copper Co. obtained an option on the Castle Dome group of claims from the Pinto Valley Co. After a little over a year of extensive surveys and exploration by churn drilling 61 holes, Miami Copper Co. exercised its option on the Castle Dome and adjoining mining properties. These properties, together with the Continental

group, were deeded to the newly formed Castle Dome Copper Co., Inc., a wholly owned subsidiary of Miami Copper Co.

Prior to the Miami Copper Co. acquiring the property in 1940, prospecting and preliminary exploration of Castle Dome involved intermittent churn drilling and tunneling lasting almost 35 years. Intensive exploration by Miami Copper Co. lasted over a year.

Castle Dome is a typical porphyry copper deposit. The principal host rock is the Lost Gulch quartz monzonite in a prominent horst structure trending north-northwesterly through the central part of the area. Mineralized intrusives including the Lost Gulch quartz monzonite, granite porphyry, and diabase are of Mesozoic or early Tertiary age and intruded the Precambrian Pinal schists and granites. Hypogene mineralization consisted mostly of pyrite and chalcopyrite and a small amount of molybdenite, sphalerite, and galena. The most abundant supergene mineral in the ore body is chalcocite; however, the enrichment is not as extensive as in the Miami-Inspiration deposit. Other minerals in the deposit included covellite, cuprite, malachite, azurite, and turquoise.

Measured on the long axis, the ore body ranged from 2,000 feet on the 4,300-foot level to 3,800 feet on the 4,085-foot level. The capping thickness ranged from a few feet to a maximum of 250 feet, averaging about 80 feet.

In late 1941, because of the urgent need for copper during World War II, the Castle Dome Copper Co., Inc., entered into an agreement with the U.S. Government through the Defense Plant Corp. (DPC), a subsidiary of the Reconstruction Finance Corp. The agreement included developing the Castle Dome ore body and constructing a concentrating plant. The Government supplied $9 million for stripping the overburden and building the plant; the concentrator was owned by and leased from the DPC. Miami Copper Co., the parent company of the Castle Dome Copper Co., Inc., supplied the additional operating capital needed after the treatment plant was completed.

The mine and concentrator were developed and constructed in a record 17 months. Rapid construction during the war years was facilitated by the availability of otherwise scarce structural steel and some heavy equipment obtained from the dismantled Copper Queen mill of the Phelps Dodge Co. at Bisbee, Ariz.

Production of 10,000 tpd was attained by December 31, 1943--35 years after the original Castle Dome Copper Co. was organized. By the end of 1944, the capacity had been increased to 12,000 tpd.

In 1953, Castle Dome Copper Co., Inc., of Miami Copper Co. declared that the ore reserves of the open pit operation were exhausted. The mine was shut down, and the concentrator was dismantled and transferred to the nearby Copper Cities Mining Co. of Miami Copper Co.

From 1943 to 1953, the period of open pit mining, Castle Dome produced 257,195 tons of copper valued at $106 million and gold and silver valued at $777,000. About 41.4 million tons of ore were mined and 48.5 million tons of

waste removed. The average grade of ore was 0.725 percent copper. The copper recovered during the dump-leach period, 1953 to 1970, totaled 32,851 tons.

Production by open pit mining methods, 1943 to 1953, and by dump leaching, 1953 to 1970, is shown in tables B-1 and B-2 in appendix B, a detailed chronological history of the development of the Castle Dome property. Table 7 summarizes this history.

TABLE 7. - Summary of the history of Castle Dome property

Activity	Date	Total time period	
		Years	Months
Location of 1st claim in Globe-Miami district to initial large-scale production of Castle Dome mine.	Sept. 19, 1873-June 10, 1943.	70	-
Location of claims in Castle Dome area to initial large-scale production of Castle Dome mine.	Ca. 1905-June 1943.	~38	-
Early prospecting and exploration, up to acquisition by Miami Copper Co.	Ca. 1905-40........	35	-
Option period, Miami Copper Co............	Fall 1940-end 1941.	~1	-
Exploration, Miami Copper Co..............	.....do............	~1	-
Acquisition by Castle Dome Copper Co., Inc., subsidiary of Miami Copper Co., to initial large-scale production.	Fall 1940-June 1943	2	~9
Mine development: Open pit, removal of overburden to production.	January 1942-June 1943.	1	5
Concentrator construction (design capacity: 10,000 tpd).	.....do............	1	5
Expansion to 12,000 tpd....................	December 1943-late 1944.	~1	-
Open pit mine period......................	June 1943-December 1953.	10	6
Leaching period to date....................	1953-70...........	17	-

Copper Cities Property (10, 24, 37, 51, 61, 70)

The Copper Cities mine is on the south flank of Sleeping Beauty Peak, in sec 12 (unsurveyed), T 1 N, R 14 E, and sec 7, T 1 N, R 15 E, about 3-1/2 miles north of Miami, Gila County, Ariz. The original surface altitude ranged from 4,250 feet to 3,870 feet at the Tinhorn Wash on the southern limits of the mine. The climate is semiarid.

The mine was brought into large-scale production by Miami Copper Co. in 1954. Miami Copper Co. was acquired by Tennessee Corp, in 1960; Tennessee Corp. was merged with Cities Service Co. in 1963.

Prospectors and companies first made sporadic attempts to recover gold in the Lost Gulch area and surrounding territory north of Miami in the 1880's,

and then again in 1896. Before 1954, the production efforts did not succeed for various reasons such as scant water supply, unsatisfactory metallurgical treatment, and the fact that capital was depleted for acquisition of property. Reorganizations brought new money, new acquisition of properties, and renewed exploration efforts; one such reorganization led to an investigation of mineral deposits on the flank of Sleeping Beauty mountain.

Historical development of the Copper Cities deposit begins in 1896 with the activity of the Girard Mining Co., which was reincorporated as the Lost Gulch Mining Co. the same year. The following year that company was reorganized as the Lost Gulch United Mines Co.; its property included 19 claims consisting of 283 acres in three contiguous groups 2 miles north of the mouth of Lost Gulch. That same company became the Louis d'Or Mining Co. in 1912. Examination of the Lost Gulch area by eastern interests led to investigation of mineralization on the south flank of Sleeping Beauty Peak and eventually to a recapitalization in 1915 and subsequent reorganization of the company a year later. In 1912 the copper values, not recoverable if the ore were treated by the cyanidation process for gold only, were deemed inadequate for treatment alone.

With the reorganization in 1916, the company was renamed Louis d'Or Mining and Milling Co. An exploration program, initiated in 1917 and continued to about 1922, included 12 churn-drill holes totaling 9,000 feet and several shafts and tunnels. Based on information derived from the drilling program, the company estimated the deposit to contain 150 million tons of ore ranging from 1 to 1.5 percent copper. By 1926, the property, consisting of about 2,800 acres, included 65 claims (30 patented) of the company, 77 claims purchased from Inspiration Miami Copper Co., and 5 claims purchased from Inspiration Miami Extension Co. However, the capitalization increase in 1921 did not bring in sufficient money to finance the acquisitions and development of the property. Plans had been formulated to deepen the shaft to 800 feet and to construct a 12,000-tpd concentrator and auxiliary facilities at an anticipated cost of $8 million. In 1928 the company's assets were sold to satisfy notes. Pinto Valley Co., exploring in the Castle Dome and Pinto Valley parts of the district, advanced funds to the "note holders' protective committee" for the purchase of the property.

The noteholders and Pinto Valley Co. organized Porphyry Reserve Copper Co. to manage the properties. During the Depression years, Pinto Valley Co. encountered financial difficulties; although Porphyry Reserve Copper Co. shipped ore intermittently, monetary problems developed and many unpatented claims were allowed to lapse. In 1942, the claims still held by Porphyry Reserve Copper Co. were purchased at a sheriff's sale by Copper Cities Mining Co., a newly formed subsidiary of Miami Copper Co. The company also bought most of the relinquished claims, which had been relocated by various people.

Prospecting and preliminary exploration of the Copper Cities deposit lasted over 46 years; the time period to large-scale production was approximatley 58 years. Intensive exploration by Copper Cities Mining Co., commenced in 1943, was interrupted by a manpower shortage the same year. Churn

drilling, resumed in 1946, continued for 3 years. The total initial systematic exploration period was 4 years.

The Korean conflict beginning June 1950 stimulated Government and industry to increase copper supplies. By November 1950, a $7.5 million loan with the Reconstruction Finance Corp. (RFC) was negotiated for developing the deposit. The program was planned to purchase the Castle Dome plant and equipment from RFC; after depletion of the Castle Dome deposit, the concentrator and other facilities would be transferred to prepared sites at the Copper Cities property. Utilization of Castle Dome mining equipment allowed considerable savings in capital costs and construction time. This savings was a factor in the decision to bring the deposit into production. In 1951, under the Defense Production Act, Copper Cities Mining Co. executed a purchase contract with the General Services Administration. The Government was committed to purchase a maximum of 170 million pounds of copper at 23 cents per pound (if the company was unable to sell copper at a price equal to or higher than the contract price). The company repaid the loan in 1954, and no purchases of copper were made by the Government.

Preparation of the mine site, including removal of overburden, occurred between 1951 and 1954. Beginning in December 1953, the concentrator was dismantled at Castle Dome and transferred to the Copper Cities deposit, where production was begun 8 months later (August 1954). Full production of 12,000 tpd was attained in another 3 months. Development of the open pit mine took 3 years and 2 months; construction of the mill required 8 months. A molybdenum circuit was added in 1968.

Similar to the Castle Dome deposit, the Copper Cities porphyry copper is found principally in the highly fractured Lost Gulch quartz monzonite, in a granite porphyry, and, to a lesser degree, in a diabase. These intrusives are in a horst block; the ore body is bounded by faults on the west, east, and north sides. Principal hypogene minerals are quartz, pyrite, chalcopyrite (the most important ore mineral), and molydenite. Chalcocite and covellite are the supergene sulfide minerals in the deposit. Other minerals in the deposit include malachite, azurite, and turquoise.

In 1965, the exposed part of the ore body was over 2,000 feet long and 1,000 feet wide in the northwest, and 2,000 feet wide in the southeast. The ore ranged from 100 to 400 feet in thickness, averaging about 200 feet. The grade of the ore in 1965 was 0.7 percent copper; however, by 1972 it had dropped to 0.5 percent copper. The molybdenum sulfide content in 1972 was 0.0007 percent.

Open pit production of copper ore from 1954 through 1971 totaled 61,725,501 tons; recoverable metals included 336,112 tons of copper with small amounts of molydenum, gold, and silver. From 1962 to 1971, an additional 18,214 tons of copper was obtained by dump leach. Production of copper is shown in table C-1 in appendix C, a detailed history of the development of the Copper Cities property. Table 8 summarizes the history of the property.

TABLE 8. - Summary of the history of Copper Cities property

Activity	Date	Total time period	
		Years	Months
Location of 1st claim in Globe-Miami district to initial large-scale production of Copper Cities mine.	Sept. 19, 1873-August 1954.	81	-
Early prospecting, exploration, and production in area to initial large-scale production of Copper Cities.	Ca. 1896-August 1954.	~58	-
Acquisition by Copper Cities Mining Co., subsidiary of Miami Copper Co., to initial large-scale production.	1942-Aug. 2, 1954..	~12	-
Exploration by churn drill.................	1943, 1946-49......	~4	-
Mine development: Open pit, removal of overburden to production.	June 1951-Aug. 2, 1954.	3	2
Concentrator construction (design capacity: 12,000 tpd).	Dec. 4, 1953-Aug. 2, 1954.	-	8
Leaching period..........................	December 1962-1972.	10	-

Initial exploration to 1949 outlined 33,800,000 tons of ore with an average grade of 0.7 percent copper at a cutoff grade of 0.4 percent copper. In 1956, 9.5 million tons of slightly lower grade ore were added to the initial reserve estimate. As of January 1959, ore reserves were estimated to be 29,220,000 tons with an indicated waste-to-ore ratio of 0.26 to 1.00.

San Manuel Property (11, 15, 30, 32-33, 36, 42, 58, 63, 71)

The San Manuel mine is in T 85 S, R 16 E, in the Old Hat (Mammoth) mining district, 45 miles northeast of Tucson and 7 miles northwest of the San Manuel townsite in southeastern Pinal County, Ariz. The mine, located between the Black Range and Santa Catalina mountains, is in a pediment that slopes northeasterly to the San Pedro River. Altitudes in the immediate area range from 3,450 feet on Red Hill to 2,400 feet at the San Pedro River. The climate is semiarid.

The San Manuel operation, a division of the Magma Copper Co., wholly owned by Newmont Mining Corp., includes the San Manuel mine, concentrator, smelter, refinery, and continuous-casting rodmill. The Kalamazoo property, immediately west of the San Manuel mine, was acquired by Magma Copper Co. from Quintana Minerals, Ltd., in 1968.

The San Manuel-Kalamazoo is a typical porphyry copper deposit. The principal mineralized host rock includes the Precambrian porphyritic quartz monzonite (Oracle granite), a late Cretaceous quartz monzonite porphyry, and to a lesser extent, a late Cretaceous or early Tertiary diabase. Chief ore minerals are chalcopyrite, chalcocite, pyrite, and molybdenite. The original San Manuel ore body was an oval cylinder, some 2,500 by 5,000 feet in cross

section and about 8,000 feet in height, which had a barren core. The alteration area extends some 3,000 to 5,000 feet beyond the ore and follows a distinctive horizontal and vertical pattern. The deposit is postulated to have been tilted following deposition and then faulted into two roughly equal-sized segments, the San Manuel and the down-faulted Kalamazoo. The top of the Kalamazoo ore body, 2,500 feet below the surface, has an overturned canoe shape, apparently the mirror image of the San Manuel. The boat-shaped San Manuel ore body North limb averages 400 feet wide; the South limb is up to 1,000 feet wide. The entire deposit is almost entirely overlain by Gila conglomerate and some weakly mineralized monzonite. The capping over the San Manuel portion ranges up to 1,900 feet and averages 670 feet deep.

As of 1969, San Manuel ore body reserves were estimated to be 496.8 million tons of sulfide ore of 0.728 percent copper and 130 million tons of oxide ore of 0.7 percent copper. The Kalamazoo ore body was estimated to contain 565 million tons of sulfide ore averaging 0.72 percent copper.

Prospecting in the Mammoth (Old Hat) area reportedly began before the Civil War. The first claims, Hackney and Aaven, were staked in 1879; the Mohawk, Mammoth, and Mars claims were staked in 1881-82. These claims, 1 mile north of the present San Manuel operation, were on vein deposits typical of those often found on the periphery of disseminated porphyry coppers. The mines were operated intermittently through the years: the first production period, 1882 to 1912, was for the recovery of gold; the second production period, 1916 to 1919, was stimulated by World War I, with the mines reopened for the recovery of molybdenum; the third production period began in 1934 with the increase in the price for gold. Between 1934 and 1943, lead, vanadium, molydenum, and gold were obtained from the oxidized vein deposits of the Mammoth, Collins, and Mohawk-New Years properties. Because the reserves of oxide ores were declining, mining stimulated by World War II consisted primarily of extracting lead-zinc sulfide ore from the mines. With increasing depth, the grade of the ores decreased; the Mammoth-Collins properties were closed in 1952 because of depleted reserves and the influx of water on the lower levels. In 1953, Magma Copper Co. acquired these properties which by then were known as the St. Anthony Mining and Development Co., Ltd.

In the immediate San Manuel area, claims were stakes on Red Hill and reportedly held more or less continuously from 1906. From 1915 to 1917, the William Boyce Thompson interests churn-drilled two holes on some chrysocolla outcrops southeast of Red Hill. Exploratory work was discontinued because the ore was low grade.

Anselmo Laguna located the original claims on the San Manuel ground in 1925. Through the years James M. Douglas, R. Burns Griffin, Victor Erickson, and Henry W. Nichols prospected the property and tried to persuade others to explore and develop the ground. In 1942, a report was submitted to the Reconstruction Finance Corp. (RFC) for obtaining a $20,000 loan for exploration prior to building a mill; the RFC rejected the loan. However, because of conditions during World War II, the property was brought to the attention of other Government agencies, including the War Production Board. In March 1943, the

U.S. Geological Survey made a preliminary study and recommended that the Bureau of Mines drill the area. The Bureau of Mines commenced drilling November 1943; by May 1944 reports of sulfide mineralization discovered in the No. 6 hole reached Magma Copper Co. This information generated enough interest for the company to reexamine the property and obtain an option and purchase agreement to explore the ground for 1 year. Magma Copper Co. began its own exploration program, including churn drilling and underground exploration. At the end of the 1-year option period, Magma exercised its right to purchase the property and then formed a subsidiary, San Manuel Copper Corp., to operate it.

The prospecting phase, lasting 18 years, began in 1925 and continued until 1943. Exploration of the San Manuel ore body totaled over 9 years. Intensive exploration by surface drilling approximated 5 years, 2 years by the Bureau of Mines and about 3 years by Magma Copper Co. Underground exploration was begun when the first shaft was collared March 1948 and was concluded when the RFC granted a loan for development in July 1952.

The development period could also include part of the exploration period. However, the major mine development period is considered to have begun about January 1953 and to have continued to January 1956 when the first undercut was completed and production by the block-cave system of underground mining started. Exploration and development by Magma Copper Co. alone required over 11 years to bring the mine into production.

In 1956, production was obtained at San Manuel, 12 years after the property was optioned by the company; this was 13 years after the discovery of mineralization in the Bureau of Mines drill holes, 31 years after the original claims were staked by Anselmo Laguna, and 77 years from the date the original claims were staked in the Old Hat district.

The San Manuel mine was brought into production after some 7-3/4 years of development and construction. The period extended from March 1948 with the collaring of the first shaft, which was used for exploration and later for development work, to January 1956 when the first stope undercut was completed. Construction for the operation included five shafts and over 20 miles of drifts, mine-surface plants, 30,000-tpd concentrators, 360,000-tpy smelters, 7 miles of standard-gage railroads, and a townsite with 1,050 homes, shopping facilities, hospital, and schools.

The underground block-cave mining method required careful planning of the subsidence area, which by 1972 was 6,400 feet long and 4,000 feet wide.

Magma Copper Co. advanced San Manuel Copper Corp. $10 million for the initial exploration and the beginning exploration-development program. Most of the mine development, plant construction, and auxiliary facilities were financed with a $94 million loan from the RFC granted during the Korean conflict. Construction of the townsite and homes by Del E. Webb Construction Co. and M. O. W. Homes, Inc., was a separate $10 million transaction. In 1963, refinancing through Prudential Insurance Co. of America allowed the RFC loan to be retired.

In addition to the RFC loan commitment, the company also made an agreement with the Defense Materials Procurement Agency whereby the Government would purchase 347,500 tons of copper at a floor price of 24 cents per pound plus escalation. The company, however, could sell on the open market when prices were higher than the Government contract price. By June 30, 1974, 79,117 tons in the amount of $42,921,000 had been delivered to the Government; "put" rights not used included 268,383 tons at a total value of $147,325,000. The guaranteed price provided an additional incentive in the development of the mine.

The first expansion period from January 1964 to July 1965 brought production up to 40,000 tpd. The second expansion period was authorized in July 1968; by the end of 1972, production averaged 61,440 tpd. This expansion included sinking three shafts from the surface, deepening two shafts, and constructing a 200,000-tpy electrolytic refinery and a 100,000-tpy continuous-cast rodmill. In March 1968, the second expansion was the result of increased ore reserves with the acquisition of the Kalamazoo ore body.

About $102 million was required to bring the San Manuel mine into production by the end of 1956; this total capital expenditure included the property, deferred development, plant, and railroad. The first expansion was estimated to cost over $11 million; the second, which included both San Manuel and Superior (divisions of Magma Copper Co.), reportedly cost over $250 million. San Manuel production was increased from 40,000 tpd to over 60,000 tpd; Superior production went from 1,500 tpd to 3,300 tpd.

Production expansion and institution of new Federal and State environmental pollution regulations required modification of the smelting facilities and construction of additional structures. In 1973 the cost of compliance with the new regulations was estimated to be $47 million.

The prospecting or preliminary-exploration period of the Kalamazoo ore body began in 1946 when claims were staked by Frank F. Salas, R. A. Buzan, H. G. Buzan, and W. C. Buzan of Mammoth, Ariz. During the following 11 years, seven churn-drill holes were put down to depths between 1,400 and 2,850 feet on ground optioned by Martha Purcell. Because no ore was intersected exploration was suspended. From 1965 to 1967, Quintana Minerals Corp., which had acquired the property, resumed exploration; 25 holes drilled to depths averaging 4,000 feet resulted in the discovery of mineralization similar to the San Manuel deposit.

At Kalamazoo, the period from the location of the mining claims through Quintana's exploration and discovery period was 21 years, including 11 years of preliminary exploration and 2 years of exploration from the surface. Underground exploration and development are currently underway; production is expected in 1979 or 1980.

A detailed history of the San Manuel and Kalamazoo properties is contained in appendix D; a summary of these details is listed in tables 9 and 10.

TABLE 9. - Summary of the history of San Manuel property

Activity	Date	Total time period Years	Total time period Months
Area reportedly worked	Ca. 1870-79	9	-
First claims staked in Old Hat mining district to initial large-scale production	1879-1956	77	-
Early prospecting, exploration, production from nearby claims to acquisition by Magma Copper Co.	1879-1944	65	-
First claims located on Red Hill in San Manuel area to initial large-scale production of San Manuel.	1906-56	50	-
Original San Manuel claims (Nos. 1-5), date located to initial large-scale production.	1925-56	31	-
Preliminary exploration by U.S. Bureau of Mines and U.S. Geological Survey.	March 1943-February 1945.	1	~11
Acquisition by Magma Copper Co. to initial large-scale production.	Aug. 31, 1944-Jan. 11, 1956.	11	4
Option period, Magma Copper Co	Aug. 31, 1944-Sept. 17, 1945.	1	-
Exploration by surface churn drilling	December 1944-February 1948.	3	2
Exploration and development underground period.	Mar. 17, 1948-Ca. July 1952.	4	~4
Major mine development to production	January 1953-January 1956.	3	-
Concentrator construction (design capacity: 30,000 tpd).	Ca. July 1953-Oct. 5, 1955.	2	~3
Expansion:			
To 40,000 tpd	January 1964-July 1965.	1	7
To 60,000 tpd	Spring 1969-November 1971.	2	~9
Smelter construction (100,000-tpy capacity).	1953-June 8, 1956	~3	-
Smelter expansion to 200,000 tpy	Planned	NAp	NAp
Refinery construction (200,000-tpy capacity).	March 1970-December 1971.	1	9

NAp--Not applicable.

TABLE 10. - Summary of the history of Kalamazoo property[1]

Activity	Date	Total time period, years
First claims staked in Old Hat mining district to initial large-scale production.	1879-1957............	78
Claims staked on the Kalamazoo property to projected large-scale production.	1946-(1980)..........	(~34)
Preliminary exploration by Mrs. Martha Purcell.	1946-58..............	~12
Exploration by Quintana Minerals Corp......	1965-67..............	~2
Location of claims to acquisition by Magma Copper Co.	1946-68..............	22
Acquisition by Magma Copper Co. to initial large-scale production.	March 1968-(1980)....	(~12)
Mine exploration: Underground............	1968-(?).............	?
Mine development..........................	November 1968-(1980).	(~12)

[1] Projected data are given in parentheses.

Twin Buttes Property (1, 5, 6, 7, 8, 29)

The Twin Buttes mine is in T 18 S, R 13 E, in the Pima mining district, Twin Buttes area, Pima County, about 25 miles south of Tucson, Ariz. In 1972, The Anaconda Co. held the property on a long-term lease from Banner Mining Co. However, in 1973 Banner merged with American Metals Climax, Inc. (AMAX); negotiations between AMAX and Anaconda resulted in forming a 50-50 joint enterprise called Anamax Mining Co. Topographic relief in the immediate vicinity is relatively low, and the average altitude is about 3,350 feet. The climate is semiarid.

The ore deposit is overlain by 400 to 600 feet of alluvium with a conglomerate up to 50 feet thick at the base and an oxidation zone varying up to several hundred feet in thickness. The principal ore mineral is chalcopyrite, which occurs with other sulfide minerals including sporadic molybdenite in the primary ore zone. The important oxide ore minerals are chrysocolla and tenorite or melaconite, with cuprite and native copper locally plentiful. Other minerals noted in the deposit were pyrite, magnetite, sphalerite, galena, chalcocite, brochantite, and malachite.

About 73 years of sporadic prospecting, exploration, and small-scale production preceded acquisition of the properties in the area by Banner Mining Co. in 1950. In 1951, with the assistance of a Defense Minerals Exploration Administration contract, exploration was resumed at the old Copper Glance (Twin Buttes) mine. Banner Mining Co. advanced $67,895, as did the Government on an equal participation basis. Geophysical exploration in 1956 discovered an anomalous area nearby. By 1963 Banner had assembled a large block of claims in the Twin Buttes area and entered into a long-term agreement with Anaconda for exploration of the properties. The exploration and development

by Anaconda extended from 1963 to 1967. Exploratory drilling amounted to 193 holes totaling 321,377 feet drilled from the surface and 73 holes totaling 45,339 feet drilled from underground. An exploration shaft was put down 956 feet to observe the geology and to obtain bulk samples of ore for pilot plant tests. By March 1965, results of the detailed exploration and testing program were sufficiently encouraging to proceed with the development of an open pit mine. Stripping operations commenced in July of the same year; by the end of September 1969, 246,196,216 tons of alluvium and 20,312,626 tons of conglomerate, waste rock, and ore had been removed to the dumps or stockpiled.

Development of the mine by Anaconda required 4 years because of the extraordinary amount of overburden removed to expose the low-grade deposit. The design of the mining operation incorporated an unusual transportation system in which the material is crushed in the pit and transported by conveyor belt to the waste, leach, or concentrator areas..

Concentrator construction began in August 1967; the first units produced copper concentrates in September 1969. The molybdenum recovery plant commenced operation in May 1970. The first full year (1970) of production yielded 175,751,527 pounds of copper, 265,607 pounds of molybdenum, and 1,206,310 ounces of silver.

By the end of 1971, a stockpile of over 25.6 million tons of oxidized copper material at the mine was awaiting development of an effective recovery process. The oxidized minerals in a limestone gangue, not recoverable in the conventional sulfide mill, will require relatively large amounts of sulfuric acid for leaching.

Development of the Twin Buttes property from preliminary exploration by Banner through production from the open pit by Anaconda required about 19 years. Exploration and development of the property by Anaconda required over 6 years and an investment of some $200 million.

The extensive exploration by Banner, that company's lease negotiations with Anaconda resulting in the initial development and production by Anaconda, the acquisition of Banner by AMAX, and the subsequent joint venture involving financial, property, and operating agreements between Anaconda and AMAX illustrate the tremendous quantity of money and time necessary to develop this type of deposit. The deposit, deeply buried for open pit mining methods, is geologically complex, and the ore is metallurgically difficult to treat. In addition to the $200 million and 6 years previously expended in bringing the deposit into production, the joint venture of AMAX and Anaconda called for the development of new reserves, expansion of the concentrator, and the initiation of a new process to treat the oxide ore; these changes were estimated to cost an additional $244 million and 3 years.

Table 11 summarizes the history of the Twin Buttes property; a detailed history of the property is in appendix E.

TABLE 11. - Summary of the history of Twin Buttes property

Activity	Date	Total time period	
		Years	Months
First claims located at Twin Buttes camp, Pima mining district, to large-scale production.	Ca. 1876-1969......	93	-
Early prospecting, exploration, and production from nearby claims.	1876-1949?.........	73?	-
Banner Mining Co. exploration in area......	1950-63............	13	-
Geophysical anomaly found by Banner in the Twin Buttes area.	1956...............		
Acquisition by Anaconda to initial large-scale production.	March 1963-September 1969.	6	6
Preliminary evaluation and option period--Anaconda.	March 1963-April 1964.	1	1
Exploration period--Anaconda (surface and underground).	March 1963-March 1965.	2	-
Mine development: Open pit, removal of overburden to production.	July 1965-September 1969.	4	2
Concentrator construction (design capacity: 30,000 tpd).	August 1967-September 1969.	2	1
Expansion to 32,000 tpd....................	Planned 1971.......	NAp	NAp

NAp--Not applicable.

Summaries of Additional Properties

Pinto Valley Property (10, 37, 65)

The Pinto Valley property of Cities Service Co. lies on Porphyry Mountain near the Castle Dome mine, Gila County, Ariz.

Little has been written on the early history of this property; however, it was reportedly acquired by the Miami Copper Co. sometime in the 1920's. According to an annual report, the Miami Copper Co. in 1941 exercised its option on the Castle Dome group and "adjoining mining properties" which may have included the Pinto Valley property. Miami Copper Co. and later Cities Service Co., which acquired Miami Copper Co. in 1963, held the Pinto Valley area in abeyance. Cities Service started development of the Pinto Valley mine in 1972 so as to attain full production by December 1974. Output from the new operations will replace that from the company's Copper Cities open pit, which had been in production since 1954 and was phased out in 1975.

The time span from the location of the nearby Continental mine, about 1881, to large-scale production of the planned Pinto Valley mine is about 93 years; based on the early claims located in 1905 on Porphyry Mountain, the period would be 69 years. The Continental group of claims, covering the east end of the Castle Dome ore body, was acquired by Miami Copper Co. with the purchase of the Old Dominion Co. properties in 1941.

Exploration in the Pinto Valley area, which was deeper and to one side of the Castle Dome deposit, began in 1961; by 1969, 158 holes had been drilled totaling 230,000 feet. After a 2-year feasibility and economic study, Cities Service Co. committed $100 million to bring the mine into production.

Initial preparation for mine development began in May 1972; stripping of 56 million tons of overburden commenced by August eventually reached a rate of 125,000 tpd. Approximately 500 feet of material was removed from the top of Porphyry Mountain. Mining at the start of production was expected to be 60,000 tpd of waste and leaching material and 40,000 tpd of ore. Mine development from stripping of overburden to initial large-scale production was estimated to require 2 years.

The concentrator construction period was estimated to take 2 years to reach 20,000-tpd initial capacity of the first unit in July 1974. The designed capacity, 40,000 tpd, was expected to be reached in late December 1974, after the second unit of the concentrator had been completed.

Reserves of the Pinto Valley deposit have been estimated at 350 million tons of ore averaging 0.44 percent copper.

Miami East Property (10, 37, 65)

From 1923 to 1925, Miami Copper Co. explored the area east of the Miami fault; although diamond drilling from the Miami underground mine penetrated "good ore," no deposit of "merchantable ore large enough to warrant exploitation was found" (Miami Copper Co. annual report 1924). Tonnage was not estimated at that time. In the 1940's, some surface drilling was undertaken in the area; resumption of drilling in 1968 resulted in the discovery of additional mineralization in April 1969. On the basis of 8 of 10 drill holes completed by 1970, the deposit was estimated to be at depths ranging from 2,460 to 3,800 feet and between 150 and 645 feet thick.

Beginning in April 1970, the old Miami Copper No. 5 was deepened from 1,120 feet to 3,500 feet by January 6, 1973, to permit evaluation of the ore body. Development work, begun in January 1973 on the 2,900- and 3,300-foot levels, was in progress December 1974. Two exhaust shafts, begun in January 1973, were still under construction as of December 1974.

Located about 2,000 feet east of the old Miami deposit, the Miami East ore body has been estimated to contain 55 million tons averaging 1.95 percent copper. The ore body is reportedly 3,000 feet long, 1,200 feet wide, and up to 400 feet thick, and dips to the north and east with a maximum pitch of 34°.

The mine was being developed for the cut-and-fill mining method to produce 5,000 tpd beginning in 1975. Ore will be treated in the company's Copper Cities concentrator, which is about 10 miles away.

A minimum of 5 years has been required to deepen the Miami No. 5 shaft and to bring the mine to production. From the discovery of "good ore" in the Miami East area about 1923 to projected large-scale production in 1975, the time span approximates 52 years; from the discovery of mineralization by surface drilling in 1969 to the projected 1975 production date, the period is 6 years.

Pima Property (13-14, 64, 72)

Mineralization in the Santa Cruz Valley was noted by Father Eusebio Francisco Kino, who founded the mission San Xavier del Bac in 1700. The early Spaniards worked the deposits in a small way for lead and silver.

Early mining (1880-1900) in the Pima district included the San Xavier, mined for lead and silver; the Olive, mined for gold and silver; and Mineral Hill and Twin Buttes, mined for copper and gold.

Recent exploration for copper in the Pima district was initiated with a preliminary exploration program which included a literature search, geophysical survey, and discovery and confirmation by drilling in the early 1950's. United Geophysical Co. financed the original 2-year exploration program. In 1951, Pima Mining Co. was organized by Union Oil Co. of California to explore and develop the Pima ore body. Underground exploration for 5 months resulted in production beginning May 1952. In August 1955, Cyprus Mines Corp. exercised its 1-year option to purchase a 75-percent interest in the property; Union Oil retained the remaining 25 percent. Cyprus later sold 25 percent of its interest to Utah Construction Co.

Underground development and mining of high-grade ores continued through October 1955, when the company decided to mine the larger resources of lower grade material by open pit. Development and construction of the open pit operation required just over a year. From the time Pima Mining Co. acquired the property in 1951 to the time the open pit reached full production was about 6 years.

Construction of the designed 3,000-tpd concentrator was begun in December 1955 and completed 1 year later. The concentrator capacity was expanded in four separate stages to 53,000 tpd; expansion periods ranged from 10 months to 1 year and 7 months.

As of December 31, 1972, ore reserves at the Pima property were estimated to be 241,019,000 tons averaging approximately 0.50 percent copper and containing economically recoverable quantities of molybdenum and silver.

Esperanza and Sierrita Properties (18-19, 28, 34, 49, 62)

The Esperanza property of Duval Corp. in the southernmost part of the Pima district, Pima County, Ariz., is another example of the sporadic nature of efforts to explore and bring into production a typically low-grade copper

deposit. The area had been prospected since 1895. Its potential as a valuable disseminated porphyry copper deposit was recognized by Harrison Schmitt, who recommended the property for purchase by Duval Sulphur and Potash Co. in 1955. This company became Duval Corp. in 1963--and was later a wholly owned subsidiary of Pennzoil Co. After 4 years of major exploration and development, the property was brought into production in 1959. It was 64 years from the time the first claims were staked in 1895 until the mine was brought into large-scale production. Exploration and development of this mine were privately financed.

The Sierrita property adjacent to the Esperanza was brought into production by the Duval Sierrita Corp., a wholly owned subsidiary of Duval Corp. The development of the Sierrita property was made possible with the aid of a copper production expansion contract, signed November 28, 1967. Under the authority contained in the Defense Production Act of 1950, a program authorized by the President March 29, 1966, was inaugurated to encourage additional domestic production of copper in the interest of national security. This was during the Vietnam conflict.

The total cost of the project was estimated at $151 million to bring the mine into production. The General Services Administration was to advance $83 million (at 6 percent interest) against future deliveries of about 109,210 tons of wirebar copper which would be priced at 38 cents per pound. In addition GSA guaranteed a privately obtained loan of $48,750,000 at an initial guaranteed rate of 70 percent of the principal. The balance of the total cost was to be supplied by Duval Corp., including $3.5 million already expended on the project. The contract runs through June 30, 1979. By June 30, 1974, about (26,244,000) had been delivered to the Government.

The period from acquisition to production lasted about 6 years including 1 year for major exploration and 2 years for development. One lapse in the time interval occurred because negotiation of the Government loan required nearly 2 years. Feasibility and planning studies were made during that time span.

As of December 31, 1969, ore reserves at the Esperanza mine were estimated to be 27,667,000 tons, averaging 0.43 percent copper and 0.035 percent molybdenum. The Sierrita property ore reserves were estimated to be 414 million tons, averaging 0.35 percent copper and 0.035 percent molybdenum.

Mineral Park Property (18, 20, 27, 48-49, 57)

The Mineral Park (Ithaca Peak) property of Duval Corp., a wholly owned subsidiary of Pennzoil Co., is in the Mineral Park mining camp of the Wallapai mining district, Mohave County, Ariz.

Indians mined turquoise in the Mineral Park area, perhaps 500 or more years ago, as evidenced by stone artifacts uncovered in ancient trenches and narrow adits. In the 1850's, various expeditions traversing the area noted the mineral deposits of the Cerbat Range; the first claim located in the

Mineral Park area of this range was the Mayflower in 1870, followed by the Keystone claims. The Keystone mine shipped the richest ore in the county and intermittently produced silver, gold, and copper-lead-zinc ores from 1870 to 1948. The early mined rich silver ores of the district were shipped by wagon to the Colorado River, then by steamer to Yuma, then to San Francisco over the Southern Pacific Railroad, and finally by ship to Swansea, Wales, where they were processed.

Mining activity was curtailed in the 1880's because of declining silver prices; however, several mines continued intermittent small-scale production as late as World War II. After the war, only gem-quality turquoise mines survived. Some sporadic exploration by several companies was undertaken, until 1958 when Harrison A. Schmitt made a favorable report on the area for Duval Corp.

Between 1958 and 1962, the land-acquisition program of Duval Corp. involved gaining control of several old mines (including the Keystone) and acquiring and staking claims over intervening ground until sufficient area was obtained to justify the expenditures necessary to bring in a large-scale operation. By 1965, the property totaled 5,138 acres and consisted of 84 mining claims with patents pending, 20 patented claims, 104 unpatented claims, and some prospecting permits, millsites, and fee land.

The exploration began in March 1959. The extremely precipitous terrain created some problems in setting up drill sites; for the 5,200-foot Ithaca Peak drill site, a helicopter was used to transport men, equipment, and material. The detailed exploration program required about 3-1/4 years to complete 123 holes, of which 82 churn-drill holes (averaging 320 feet per hole) and 29 diamond-drill holes (averaging 573 feet per hole) penetrated the ore zone. An underground adit, crosscuts, and raises were driven for sampling the ore body to confirm the drill-hole data.

The mine development period commenced in November 1962, when the first mining equipment was moved in. Stripping the estimated 23 million tons of overburden and waste from the ore horizons commenced in January 1963 and was completed by October 1964. Construction of the designed 12,000-tpd mill was completed in 1 year and 7 months. The time period from acquisition to large-scale production was 6 years.

As of December 31, 1969, ore reserves were estimated to be 39,749,000 tons averaging 0.47 percent copper and 0.047 percent molybdenum.

CONCLUSIONS

This study of the historical data of selected copper properties indicates the failures as well as the successes of men to extract economically the minerals necessary to our economy. The time span from the location of claims to large-scale production is the summation of many leadtimes of several different operations; each interval contributes substantial information necessary to the successful production of the metal. The span also included times when the mines lay dormant after funds were depleted from efforts to

gain sufficient land to make an exploration program worthwhile, when exploration failed to find adequate reserves, when deposits located were not amenable to recovery by known metallurgical technology, or when production came at a time of low metal prices.

Most of these historical factors that contributed to the length of the leadtime persist. Sufficient land must be obtained for an economic operation and its acquisition may entail years of negotiation; larger companies are better able to tolerate this delay than small companies or individuals. Today, however, these factors involve not only individual claim owners and companies, but also State and Federal Governments.

Many State Governments now have set up exploration regulations requiring time for the company or individual to submit plans and post bonds, and for the agencies to process the applications and make technical examinations of the area. Currently, construction of access roads on National Forest land requires permission from the Forest Service. Regulations now require the Forest Supervisor to approve plans for any intended operation that might cause a significant disturbance of the environment. On public land, any surface-disturbing exploration or prospecting for leased minerals such as coal or phosphates requires an application, an exploration plan, and bonding before authorization is granted by the Federal Government. (Copper, however, is a commodity not covered by the leasing act.) Compliance with these and other government regulations, local to international, is increasing leadtime. In addition, recent proposed changes in the mining law may deter mine exploration and development.

Historic governing factors still contributing to the time span include overcoming obstacles of climate and topography to gain physical access to the area, availability of equipment and supplies, and availability of water and power.

For example, changes in land-use policies are of immediate concern to the mining industry, which may find the cost of such changes prohibitive. This is especially significant where mineralized lands have been converted to recreation, wilderness, and urbanization where cost of exploration may become excessive or exploration may be banned entirely. Many deposits, depleted of ore, contain marginal or submarginal materials that are becoming ore because of technologic improvements and higher metal prices. This is an element of time that should not be overlooked in the zoning and development of particular areas.

Financing of the exploration project as well as the construction of a mine-beneficiation plant complex is becoming increasingly demanding because of the tremendous expenditures necessary to bring a large-scale operation on-stream. The time period is also lengthened by the need for many different studies, aside from the actual delineation of ore reserves by drilling and testing. Such studies include economic, geographic, environmental, and sociological analyses; and determination of the political climate--local, national, and international. Any one of these factors may make an otherwise promising enterprise impractical.

During time of crisis the Government has enabled industry to shorten the time necessary to bring mines into production and also to stimulate production of marginal ores in order to maintain an adequate supply of copper for the Nation. Examples are the Premium Price Plan which instituted price stability and stimulated production of copper over a stipulated quota during World War II, Reconstruction Finance Loans granted for the development of many mines during World War II and during the Korean conflict, and Defense Production Act loans and guaranteed base price for metals delivered to the Government at the time of the Korean and Vietnam conflicts.

The continuing geological, mining, and metallurgical studies undertaken by the U.S. Department of Interior, Geological Survey, and Bureau of Mines have contributed substantially to shorten time spans from discovery to production of new mines and to revive old mines and mining districts.

In the properties studied, the most predictable time periods in bringing a mine into production are the mine-development phase, particularly when the ore reserves are well defined, and the concentrator-construction phase after the drill cores and bulk samples have been adequately tested and the metallurgical process has been fully developed. In these studies, the mine development or construction period for an open pit mine ranged from 1 to 4 years, Twin Buttes requiring the longest time span because of the thickness of overburden. Development of an underground mine ranged from 4 to 8 years. For beneficiation-plant construction, the time period ranged from 8 months to just over 2 years; the break-in period required an additional 3 months to 1 year.

The most unpredictable time span is the preliminary and detailed exploration period, when areas are targeted and studied and when information is amassed, assessed, and tested. This stage may often consume an inordinate amount of time, causing any minerals found to reach the marketplace under conditions not considered in the initial capital recapture program. Contributing to the unpredictability of this period are human factors involved in gaining accessibility to land, in negotiating financing, and in attitudes of management, as well as political climate (local, national, and international). For the properties studied, the detailed exploration period ranged from 1 to 8 years. If exploration and some of the development work are included, the time span would range from 1 year at Castle Dome to over 9 years at San Manuel, 13 years at Twin Buttes under the Banner management, and 2 years by Anaconda.

These studies indicate a long leadtime from the discovery of mineralization in the immediate area to the large-scale production of copper. Only the Miami and Pima mines were brought into large-scale production in a time period under 20 years; the rest ranged from 31 to 94 years despite many attempts to bring the mines into production. The efforts of the initial discoverer or claim locator may be thwarted by insufficient funds, technical knowledge, and land problems; the option should remain open for a return to the area with renewed financing or perhaps with new technology.

BIBLIOGRAPHY

1. The Anaconda Co. Annual Reports, 1964-71.

2. Anderson, M. N. Underground Mining. Min. Eng., v. 25, No. 2, February 1973, p. 54.

3. Ayres, M. O. Case History--Berkeley Hills Twin Transit Tunnels. Proc. 2d Symp. on Rapid Excavation. Sacramento, Calif., Oct. 16-17, 1969. Sacramento State College Foundation, Sacramento, Calif., 1969, pp. 10-26 to pp. 10-37.

4. Bailly, P. A. Mineral Exploration Philosophy. Min. Cong. J., v. 58, No. 4, April 1972, pp. 31-35.

5. Banner Mining Co. Annual Reports, 1957-71.

6. Beall, J. V. Copper in the U.S.--A Position Survey. Min. Eng., v. 25, No. 4, April 1973, pp. 35-47.

7. Bowman, A. B. History, Growth and Development of a Small Mining Company. Min. Eng., v. 15, No. 6, June 1963, pp. 42-49.

8. Caldwell, A. B. Twin Buttes--Anaconda's Concept for Mining and Processing a Low-Grade Copper Ore. Min. Eng., v. 22, No. 4, April 1970, pp. 51-66.

9. Chapman, E. P. Why Feasibility Studies for Very Large Low Grade Deposits. World Min., v. 26, No. 6, June 1970, pp. 16-20.

10. Cities Service Co. Annual Reports, 1963-72.

11. Creasey, S. C. Geology of the San Manuel Area, Pinal County, Ariz., with a section on Ore Deposits by J. D. Pelletier and S. C. Creasey, U.S. Geol. Survey Prof. Paper 471, 1965, pp. 30-32.

12. Cummings, J. B., and T. M. Romslo. Investigation of Twin Buttes Copper Mines, Pima County, Ariz. BuMines RI 4732, 1950, 14 pp.

13. Cyprus Mines Corp. Annual Reports, 1956, 1960-71.

14. _____. Preliminary Prospectus. Feb. 22, 1973, p. 17.

15. Dale, V. B. Mining, Milling and Smelting Methods, San Manuel Copper Corp., Pinal County, Ariz. BuMines IC 8104, 1962, 145 pp.

16. Domaas, F. B. Kidd Creek--A Huge Mining Success in Ontario. Eng. and Min. J., v. 170, No. 4, April 1969, p. 88.

17. Dresher, W. H. Issues & Discussion on National Surface Mining Legislation. Ariz. BuMines Field Notes, v. 3, No. 2, June 1973, pp. 4-7.

18. Duval Corp. Annual Reports, 1959-67.

19. Duval Sulphur & Potash Co. Annual Report, 1958.

20. Eidel, J. J., J. E. Frost, and D. M. Clippinger. Copper-Molybdenum Mineralization at Mineral Park, Mohave County. Ch. in Ore Deposits in the United States 1933/1967, ed. by John D. Ridge. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1968, v. 2, pp. 1258-1281.

21. Frazer, H. Records Tumble at Navajo Tunnel 3. Western Construction, v. 47, No. 8, August 1972, pp. 27-30.

22. Griffis, A. T. Exploration: Changing Techniques and New Theories Will Find New Mines. World Min., v. 7, No. 7, June 25, 1971, pp. 54-60.

23. Hardwick, W. R. Block-Caving Copper Mining Methods and Costs at the Miami Mine, Gila County, Ariz. BuMines IC 8271, 1965, 96 pp.

24. Hardwick, W. R., and M. M. Stover. Open-Pit Copper Mining Methods and Practices, Copper Cities Division, Miami Copper Co., Gila County, Ariz. BuMines IC 7985, 1960, 51 pp.

25. Havard, J. F. Mineral Project Evaluation. Min. Mag., v. 23, No. 4, October 1970, pp. 326-327, 329.

26. Hawkes, H. E., and J. S. Webb. Geochemistry in Mineral Exploration. Harper & Row, Publishers, New York, 1962, pp. 341, 345.

27. Jancic, T. Duval Corp. Property at Mineral Park, Arizona. Mines Mag., v. 55, No. 6, June 1965, pp. 14-16.

28. _____. How Engineering Experience, High Capacity Equipment Combine To Make Ore at Sierrita. World Min., v. 5, No. 3, March 1969, pp. 28-31.

29. Knaebel, J. B. Development of the Twin Buttes Mine. Pres. at Soc. Min. Eng., AIME Ann. Meeting, Denver, Colo., Feb. 15-19, 1970, AIME Preprint 70-AO-58, 63 pp.

30. Knoerr, A. W. (ed.). San Manuel--America's Newest Large Copper Producer. Eng. and Min. J., v. 157, No. 4, April 1956, pp. 75-100.

31. Lambert, R. N. High Speed Sinking in South Africa. Ch. in Rapid Excavation--Problems and Progress, ed. by Donald H. Yardly, Society of Mining Engineers, AIME, New York, 1970, pp. 195-214.

32. Lowell, J. D. Geology of Kalamazoo Orebody. Econ. Geol., v. 63, No. 6, September-October 1968, pp. 645-654.

33. Lowell, J. D., and J. M. Guilbert. Later and Vertical Alteration-Mineralization Zoning in Porphyry Ore Deposits. Econ. Geol., v. 65, No. 4, June-July 1970, pp. 373-408.

34. Lynch, D. W. Economic Geology of the Esperanza Mine and Vicinity. Ch. in Geology of the Porphyry Copper Deposits, Southwestern North America, ed. by S. R. Titley and C. L. Hicks. University of Arizona Press, Tucson, Ariz., 1966, pp. 267-279.

35. MacGregor, I. K. Mining Industry Supports S. 2542 and H.R. 10640. Min. Cong. J., v. 57, No. 10, October 1971, pp. 59-72.

36. Magma Copper Co. Annual Reports, 1944-68.

37. Miami Copper Co. Annual Reports, 1909-59.

38. Mining Journal. (London). June 4, 1971, p. 445.

39. Mining Magazine (London). Bringing a Mine Into Production. V. 124, No. 6, June 1971, p. 464.

40. _____. (London). September 1972, p. 319.

41. Nevada Mining Association. Re: Environmental Impact Statements. Nevada Min. Assoc. Monthly Newsletter, Feb. 15, 1972 (Included in [Proc. of] Rocky Mountain Mineral Law Foundation: A special 1-day institute, Natural Resources Environmental Law, University of Denver Law Center, Denver, Colo., Feb. 26, 1972, app. A-9).

42. Newmont Mining Corp. Annual Reports, 1968-72.

43. Parsons, A. B. The Porphyry Coppers. American Institute of Mining and Metallurgical Engineers, New York, 1933, 581 pp.

44. _____. The Porphyry Coppers in 1956. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1957, 192 pp.

45. Pay Dirt. Anaconda's Twin Buttes Mine in Full Production. No. 370, Apr. 27, 1970, pp. 4-10, 20, 22, 24, 26, 28, 30.

46. _____. AMAX. Anaconda Set Twin Buttes Expansion as Banner Deal Is Completed. No. 408, June 25, 1973, p. 7.

47. Pennzoil Co. Annual Reports, 1972-73.

48. Pennzoil United, Inc. Annual Reports, 1968-71.

49. _____. Prospectus. June 2, 1970, pp. 18-20.

50. Peters, W. C. Acquire First, Explore Last. Min. Eng., v. 22, No. 11, November 1970, pp. 75-78.

51. Peterson, N. P. Geology and Ore Deposits of the Globe-Miami District, Arizona. U.S. Geol. Survey Prof. Paper 342, 1962, 151 pp.

52. Peterson, N. P., C. M. Gilbert, and G. L. Quick. Geology and Ore Deposits of the Castle Dome Area, Gila County, Arizona. U.S. Geol. Survey Bull. 971, 1951, 134 pp.

53. Pfleider, E. P. (ed.) Surface Mining. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1968, 1061 pp.

54. Ransome, F. L. Geology of the Globe Copper District, Arizona. U.S. Geol. Survey, Prof. Paper 12, 1903, 168 pp.

55. _____. The Copper Deposits of Ray and Miami, Arizona. U.S. Geol. Survey Prof. Paper 115, 1919, 192 pp.

56. Robbins, R. J. Economic Factors in Tunnel Boring. Pres. at South African Tunnelling Conf., July 21-24, 1970, Univ. of Witwatersrand, Johannesburg, Rep. of South Africa; available for consultation at Bureau of Mines Intermountain Field Operation Center, Denver, Federal Center, Denver, Colo.

57. Schrader, F. C. Mineral Deposits of the Cerbat Range, Black Mountains and Grand Wash Cliffs, Mohave County, Arizona. U.S. Geol. Survey Bull. 397, 1909, 226 pp.

58. Schwartz, G. M. Geology of the San Manuel Copper Deposit, Arizona. U.S. Geol. Survey, Prof. Paper 256, 1953, 65 pp.

59. Seigal, H. O. Ground Investigation of Airborne Electromagnetic Investigations. 24th session, Internat. Geol. Cong., Montreal, Canada, Aug. 21-30, 1972. Proc. Sec. 9, Exploration Geophysics. International Geological Congress, Ottawa, Canada, 1972, p. 102.

60. Sheffer, H. W., and L. G. Evans. Copper Leaching Practices in the Western United States. BuMines IC 8341, 1968, 57 pp.

61. Simmons, W. W., and J. E. Fowells. Geology of the Copper Cities Mine. Ch. in Geology of the Porphyry Copper Deposits, Southwestern North America, ed. by S. R. Titley and C. L. Hicks. University of Arizona Press, Tucson, Ariz., 1966, pp. 151-156.

62. Skillings, D. N., Jr. Sierrita Copper Project by Duval in Arizona. Skillings' Min. Rev., v. 58, No. 4, Jan. 25, 1969, pp. 1, 4-5, 8.

63. _____. San Manuel Copper. Skillings' Min. Rev., v. 59, No. 9, Feb. 28, 1970, pp. 1-3, 6-9.

64. _____. Pima Mining Co. Skillings' Min. Rev., v. 61, No. 12, Mar. 18, 1972, pp. 1, 16-19.

65. _____. Pinto Valley Project. Skillings' Min. Rev., v. 62, No. 17, Apr. 28, 1973, pp. 1, 12-16.

66. Skillings' Mining Review. Kennecott's New Silicate Ore Leaching Plant at Ray, Arizona. V. 58, No. 36, Sept. 6, 1969, pp. 1, 4.

67. _____. Granduc Finishes 10.3-Mile Tunnel to Copper Deposit. V. 57, No. 52, Dec. 28, 1968, p. 8.

68. Stevens, V. L. Driving the Oso Tunnel With a Mechanical Mole. Ch. in Rapid Excavation Problems and Progress, ed. by D. H. Yardley. Society of Mining Engineers, AIME, New York, 1970, pp. 191-194.

69. Subramaniam, A. P. Operation Hardrock--A Mineral Exploration Project Based on Airborne Geophysics. 24th session, Internat. Geol. Cong., Montreal, Canada, Aug. 21-30, 1972. Proc. Sec. 9, Exploration Geophysics. International Geological Congress, Ottawa, Canada, 1972, pp. 121-134.

70. Tennessee Corp. Annual Reports, 1960-62.

71. Thomas, L. A. The San Manuel Orebody. Ch. in Geology of the Porphyry Copper Deposits, Southwestern North America, ed. by S. R. Titley and C. L. Hicks, University of Arizona Press, Tucson, Ariz., 1966, pp. 133-142.

72. Thurmond, R. E., and W. R. Storms. Discovery and Development of the Pima Copper Deposit, Pima Mining Co., Pima County, Ariz. BuMines IC 7822, 1958, 19 pp.

73. Titley, S. R., and C. L. Hicks (eds.). Geology of the Porphyry Copper Deposits: Southwestern North America. University of Arizona Press, Tucson, Ariz., 1966, 287 pp.

74. Tuck, F. J. Stories of Arizona Copper Mines. Arizona Dept. Mineral Resources, Phoenix, Ariz., 1957, 77 pp.

75. U.S. Bureau of Mines. Control of Sulfur Oxide Emissions in Copper, Lead and Zinc Smelting. BuMines IC 8527, 1971, 62 pp.

76. U.S. Forest Service. Mining in National Forests. Curent Information Rept. 14, January 1975, 20 pp.

77. Ward, M. H. Engineering for In Situ Leaching. Min. Cong. J., v. 59, No. 1, January 1973, pp. 21-27.

78. Woodcock, J. T. Copper Waste Dump Leaching. Australian Inst. Min. Met. Proc., No. 224, December 1967, pp. 47-66.

79. Yardley, D. H. (ed.). Rapid Excavation--Problems and Progress. Proc. Tunnel and Shaft Conf., Minneapolis, Minn., May 15-17, 1968. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1970, 410 pp.

APPENDIX A.--HISTORICAL DEVELOPMENT OF THE MIAMI PROPERTY

Ownership.--In 1972, the Miami property was owned by Cities Service Co. Miami Copper Co. owned the mine from its inception in 1907 until 1960, when the operation was acquired by Tennessee Corp. In 1963 Tennessee Corp. became a subsidiary of Cities Service Co.

Location (fig. A-1).--The mine is in the southeast part of T 1 N, R 14 E, near the town of Miami, in the western part of the Globe-Miami mining district, Gila County, Ariz. The Globe-Miami mining district is divided in two parts by Pinal Creek. The Globe area lies to the east of the creek in the foothills of the Apache Range; the Miami area lies to the west of the creek in the northward extension of the Pinal Range.

Climate.--Annual precipitation is about 20 inches, mostly in cloudbursts during July and August. The mean annual snowfall is 3.6 inches. Temperatures range from 13° to 110° F.

Topography.--Altitude ranges from 3,300 feet in Miami Wash to 4,000 feet along Inspiration Ridge. The topography in the Miami area is fairly rugged and irregular.

Geology (7, 17-20).[1]--Mineral deposits in the Globe-Miami district are of two types: (1) Disseminated or porphyry copper ore bodies associated with intrusives in the Miami area and (2) fissure veins in the Globe area. The Miami-Inspiration deposit lies in the Miami area.

The most important host rocks at the Miami mine are the Precambrian Pinal schist and, to a lesser extent, the porphyritic border facies of the Tertiary Schultze granite stock. The Miami deposit consists of three ore bodies: (1) The Main Miami ore body in the Pinal schist, (2) the Captain ore body in the Schultze granite porphyry, which extends west into the adjoining Inspiration mine, and (3) the Pinto ore body in the schist between the Main Miami and Captain ore bodies.

The Miami-Inspiration deposit includes the above-named ore bodies, which were mined by Miami Copper Co., and the Live Oak, Keystone, and Inspiration ore bodies mined by Inspiration Consolidated Copper Co. Apparently the deposit was originally continuous and later separated by the low-angle Bulldog fault which cut through the middle of the deposit between the Keystone and Inspiration ore bodies. The entire area had been highly fractured and hydrothermally altered. The Miami deposit was limited on the east by the Miami fault and displaced on the west by the Pinto fault. Peterson (17) suggested the Pinto and Bulldog faults could have served as channels for copper-bearing supergene solutions.

The principal ore mineral in the Miami-Inspiration deposit is secondary chalcocite formed by supergene replacement of chalcopyrite and pyrite. Quartz,

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[1]Underlined numbers in parentheses refer to items in the list of references at the end of this appendix.

FIGURE A-1

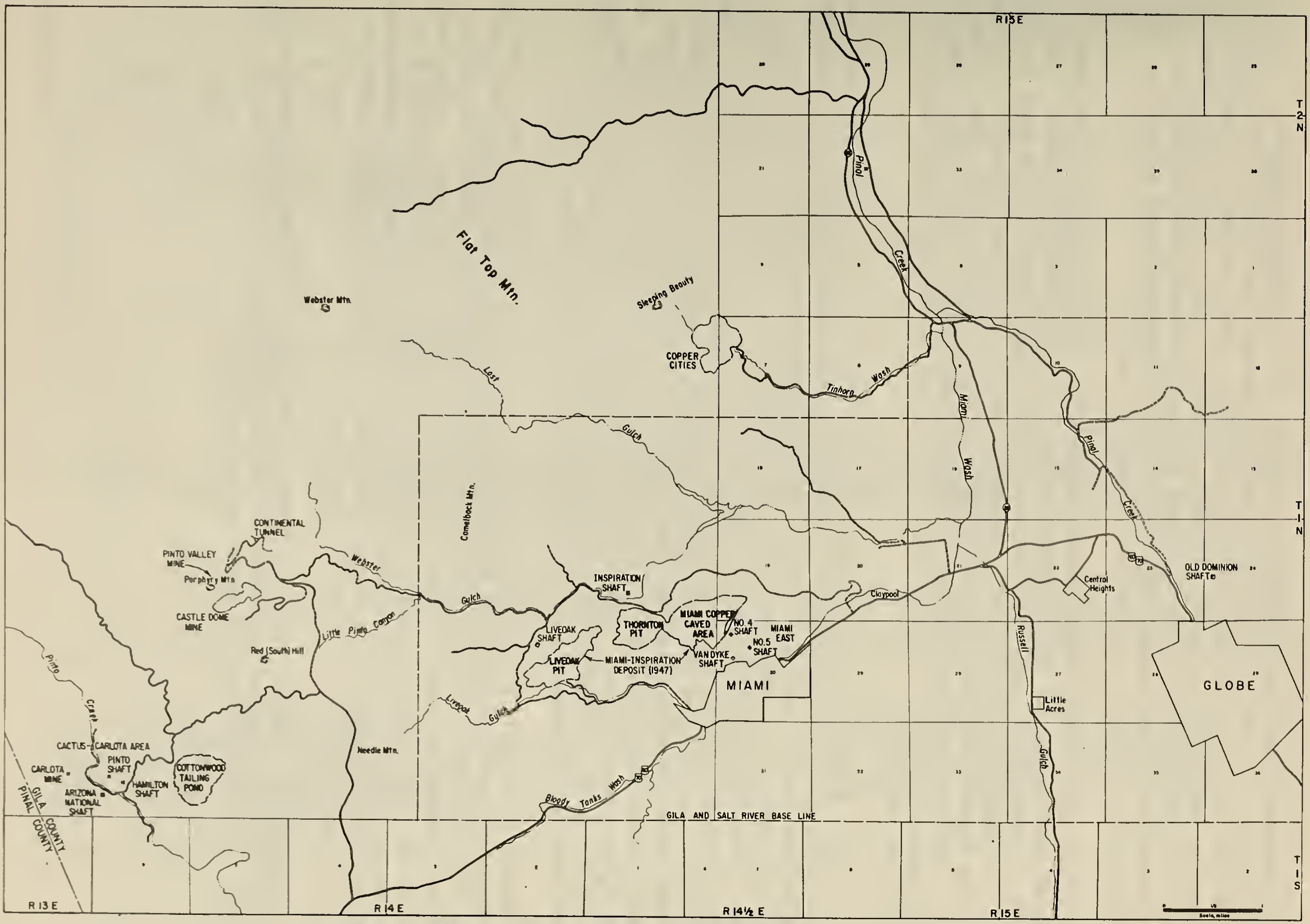

FIGURE A-1. Map showing location of selected mines, Miami area, Gila County, Ariz.

FIGURE A-1. - Map showing location of selected mines, Miami area, Gila County, Ariz.

pyrite, chalcopyrite, and molybdenite are the chief hypogene minerals. Pyrite and chalcopyrite occur with quartz in veinlets along the lightly shattered or sheeted host rocks or as disseminated particles. Small amounts of molybdenite are found as selvages on quartz veinlets which also carry pyrite and chalcopyrite. Disseminated molybdenum is found in lesser amounts in the deposit. Other minerals in the deposit include abundant chrysocolla and malachite, and a little native copper, azurite, bornite, and cuprite.

The irregular and tabular Miami-Inspiration deposit resulted from the supergene enrichment of the hypogene sulfides in the underlying rock. The deposit is overlain by a nearly barren capping ranging from a few feet to 800 feet. The boundary between the capping and the underlying chalcocite ore zone is fairly regular and roughly paralleled the land surface at the time of deposition. Chalcocite mineralization decreases with depth. The economic limits of the deposit are based on the prevailing price of copper, mining methods, and cost of production.

In 1965, Hardwick (7) described the Miami ore body as roughly triangular in plan with a base of 3,700 feet, an altitude of 2,500 feet, and a thickness of about 350 feet; capping over the ore body ranged from 250 to 500 feet. Projecting beyond the main ore body, the Northwest ore body was mined separately. The Captain ore body was about 500 by 500 feet and averaged 350 feet in thickness. In 1919, Ransome (19) noted the Pinto ore body as being a lobe about 700 feet long and 300 feet wide, projecting northwest from the Captain and Northwest ore bodies of the Miami mine. At that time he also estimated the main Miami ore body, including the Northwest and Southeast ore bodies, as being 1,600 by 1,000 feet. The Miami-Inspiration ore body together totals some 12,000 feet in length and a maximum of 2,500 feet in width; it is as much as 900 feet in thickness but averages between 200 and 250 feet thick.

Exploration east of the Miami fault, in the late 1960's, resulted in the discovery of mineralization at depths between 2,460 and 3,800 feet; the old Miami No. 5 shaft is currently being deepened to further examine the area. The Miami fault, believed to limit the Miami deposit on the east, is the west boundary of the Globe Valley fault block. The fault block was estimated to have dropped some 1,500 feet, bringing the Gila conglomerate into contact with the mineralized schist and granite on the west. The Pinal schist underlies the Gila conglomerate in the Miami East area.

Production.--Copper and molybdenum production of the Miami operation from 1911 to 1970 is detailed in table A-1 and summarized in table A-2 (4, 7, 10-12). The ores contain very little gold and silver (24).

TABLE A-1. - Miami mine production, 1911-72

Date	Type of material	Material treated, tons	Average grade, percent copper: Total	Average grade, percent copper: Oxide	Production of refined copper, pounds	Molybdenum[1] in concentrate, pounds
1909	-	Ore stockpiled	-	NAp	-	NAp
1910	-	Ore stockpiled	-	NAp	-	NAp
1911	Predominantly sulfide ore.........	445,036	2.48	NAp	15,385,783	NAp
1912	.....do...........................	1,040,744	2.39	NAp	32,832,609	NAp
1913	.....do...........................	1,058,784	2.30	NAp	32,867,666	NAp
1914	.....do...........................	1,096,633	2.28	NAp	33,296,010	NAp
1915	.....do...........................	1,348,122	2.17	NAp	41,832,059	NAp
1916	.....do...........................	1,842,017	2.07	NAp	53,518,331	NAp
1917	.....do...........................	1,640,206	2.03	NAp	43,863,699	NAp
1918	.....do...........................	2,132,941	2.03	NAp	58,407,563	NAp
1919	.....do...........................	1,698,446	2.04	NAp	54,221,638	NAp
1920	.....do...........................	1,801,958	1.97	NAp	55,581,328	NAp
1921	.....do...........................	1,868,757	1.76	NAp	53,311,941	NAp
1922	.....do...........................	2,183,020	1.88	NAp	67,454,447	NAp
1923	.....do...........................	2,380,155	1.70	NAp	64,611,145	NAp
1924	.....do...........................	2,444,079	1.12	NAp	60,475,547	NAp
1925	.....do...........................	2,919,600	1.29	NAp	51,851,274	NAp
1926	.....do...........................	3,793,207	.98	NAp	55,289,174	NAp
1927	.....do...........................	4,116,255	.85	NAp	53,038,218	NAp
1928	.....do...........................	4,260,599	.85	NAp	48,259,448	NAp
1929	.....do...........................	5,017,983	.83	NAp	58,841,159	NAp
1930	.....do...........................	6,124,993	.72	NAp	67,124,596	NAp
1931	.....do...........................	4,438,808	.70	NAp	50,572,571	NAp
1932	.....do...........................	1,417,810	.77	NAp	NA	NAp
1933	.....do...........................	Mine closed	-	NAp	-	NAp
1934	.....do...........................	Mine closed	-	NAp	-	NAp
1935	.....do...........................	837,244	NA	NAp	29,739,007	NAp
	Mixed ore.........................	1,140,447	1.67	1.08	32,827,573	NAp
1936	Sulfide ore.......................	1,763,758	.76	.25	18,407,636	NAp
	Total or average............	2,904,205	1.12	.58	51,235,209	
	Mixed ore.........................	1,562,653	1.49	.86	42,040,792	NAp
1937	Sulfide ore.......................	3,039,552	.60	.08	28,496,627	NAp
	Total or average............	4,602,205	.90	.34	70,537,419	
	Mixed ore.........................	1,761,174	1.29	.76	40,976,195	NAp
1938	Sulfide ore.......................	1,577,671	.57	.08	13,934,060	[2]$32,000
	Total or average............	3,338,845	.95	.44	54,910,255	
	Mixed ore.........................	1,735,144	1.25	.70	38,322,166	NAp
1939	Sulfide ore.......................	3,135,540	.69	.10	34,572,327	[2]$181,487
	Total or average............	4,870,684	.89	.31	72,894,493	
	Mixed ore.........................	887,777	1.12	.66	17,328,630	NAp
1940	Sulfide ore.......................	4,412,827	.66	.80	46,801,053	383,124
	Total or average............	5,300,604	.74	.18	64,129,683	
1941[3]	NA................................	NA	NA	NA	NA	NA
1942[3]	NA................................	NA	NA	NA	NA	NA
	Mixed ore.........................	218,806	1.23	.98	4,784,084	NAp
	Sulfide ore.......................	5,055,022	.70	.08	58,354,385	NA
1943[4]	Total or average............	5,273,828	.72	.11	63,138,469	
	Copper solution...................	1,209,136	.33	.33	7,548,293	NAp
	Total copper produced........	-	-	-	70,686,762	
	Sulfide ore.......................	4,717,138	.65	.10	49,701,832	618,884
1944	Copper solution...................	1,046,827	.26	.26	5,159,222	NAp
	Total copper produced........	-	-	-	54,861,054	
	Sulfide ore.......................	4,003,409	.64	.05	43,537,406	618,967
1945	Copper solution...................	1,062,577	.21	.21	4,529,256	NAp
	Total copper produced........	-	-	NAp	48,066,662	
	Sulfide ore.......................	4,222,698	.7	NAp	52,484,614	697,405
1946	Copper solution...................	1,193,118	.18	NAp	4,030,920	NAp
	Total copper produced........	-	-	NAp	56,515,534	
	Sulfide ore.......................	4,557,079	.7	NAp	51,216,361	534,082
1947	Copper solution...................	702,733	.2	NAp	2,616,880	NAp
	Total copper produced........	-	-	NAp	53,833,241	
	Sulfide ore.......................	4,197,695	.7	NAp	46,921,757	385,606
1948	Copper solution...................	712,292	.18	NAp	2,373,880	NAp
	Burch precipitates................	280	-	NAp	51,671	
	Total copper produced........	-	-	NAp	49,347,308	

See footnotes at end of table.

TABLE A-1. - Miami mine production, 1911-72--Continued

Date	Type of material	Material treated, tons	Average grade, percent copper: Total	Average grade, percent copper: Oxide	Production of refined copper, pounds	Molybdenum[1] in concentrate, pounds
1949	Sulfide ore	3,844,138	0.74	NAp	47,303,985	502,858
	Copper solution	838,593	.17	NAp	2,722,972	NAp
	Burch precipitates	1,057	10.63	NAp	211,894	NAp
	Total copper produced	-	-	NAp	50,238,851	
1950	Sulfide ore	4,003,306	.67	NAp	44,330,952	627,288
	Copper solution	546,113	.19	NAp	1,857,704	NAp
	Burch precipitates	1,369	13.93	NAp	365,122	NAp
	Total copper produced	-	-	NAp	46,553,778	
1951	Sulfide ore	3,812,045	.73	NAp	47,089,733	589,996
	Copper solution	1,044,978	.28	NAp	4,373,868	NAp
	Burch precipitates	2,839	8.98	NAp	475,809	NAp
	Total copper produced	-	-	NAp	51,939,410	
1952	Sulfide ore	3,749,162	.66	NAp	42,106,547	550,665
	Copper solution	1,146,482	.25	NAp	5,396,722	NAp
	Burch precipitates	3,321	6.03	NAp	360,837	NAp
	Total copper produced	-	-	NAp	47,864,106	
1953	Sulfide ore	3,705,113	.69	NAp	44,101,480	470,987
	Copper solution	1,232,872	.36	NAp	8,324,353	NAp
	Total copper produced	-	-	NAp	52,425,833	
1954	Sulfide ore	3,413,914	.71	NAp	38,038,346	422,592
	Copper solution	1,328,468	.28	NAp	6,884,208	NAp
	Burch precipitates	182	-	NAp	17,607	NAp
	Total copper produced	-	-	NAp	44,940,161	
1955	Sulfide ore	3,721,675	.60	NAp	33,307,266	425,239
	Copper solution	1,269,535	.24	NAp	5,628,894	NAp
	Burch precipitates	527	5.63	NAp	52,964	NAp
	Total copper produced	-	-	NAp	38,989,124	
1956	Sulfide ore	3,812,165	.67	NAp	31,911,120	492,943
	Copper solution	1,541,014	.22	NAp	6,652,909	NAp
	Total copper produced	-	-	NAp	38,564,029	
1957	Ore	3,455,120	.70	NAp	34,382,680	322,463
	Copper solution	1,623,625	.20	NAp	6,513,366	NAp
	Total copper produced	-	-	NAp	40,896,046	
1958	Ore	1,870,865	.70	NAp	17,919,666	191,913
	Copper solution	1,800,352	.21	NAp	7,481,126	NAp
	Total copper produced	-	-	NAp	25,400,792	
1959[5]	Ore	998,659	.71	NAp	10,402,912	129,841
	Copper solution	2,527,727	[6]4.43	NAp	10,826,121	NAp
	Total copper produced	-	-	NAp	21,229,033	
1960	Copper in precipitates[5]	NAp	NAp	NAp	18,930,454	NAp
1961	.....do	NAp	NAp	NAp	19,102,143	NAp
1962	.....do	NAp	NAp	NAp	18,077,492	NAp
1963	.....do	NAp	NAp	NAp	18,195,285	NAp
1964	.....do	NAp	NAp	NAp	17,757,353	NAp
1965	.....do	NAp	NAp	NAp	17,905,982	NAp
1966	.....do	NAp	NAp	NAp	17,168,489	NAp
1967	.....do	NAp	NAp	NAp	8,762,235	NAp
1968	.....do	NAp	NAp	NAp	11,076,950	NAp
1969	.....do	NAp	NAp	NAp	13,755,800	NAp
1970	.....do	NAp	NAp	NAp	14,965,326	NAp
1971	.....do	NAp	NAp	NAp	12,806,085	NAp
1972	.....do	NAp	NAp	NAp	12,170,335	NAp

NA--Not available. NAp--Not applicable.

[1]Molybdenum figures not published for 1938 (year production started), 1939, and 1941-43. Molybdenum sulfide was recovered from copper ores and converted to MoO_3.

[2]Figures published in value only.

[3]Figures for 1941-42 are still classified information.

[4]Total production from mixed ore body July 1934 to May 1943 was 9,591,299 tons averaging 1.443 percent copper (0.864 percent oxide copper and 0.579 percent sulfide copper); a total of 248,793,924 pounds of copper was obtained during the period.

[5]Underground mine closed July 1, 1959. Production from 1960 to 1970+ by inplace leaching of previously mined areas.

[6]Pounds per ton.

Sources: Arizona Department of Mineral Resources. Copper Industry Statistics (1).
Miami Copper Co. Annual Reports 1909 through 1959 (11).

TABLE A-2. - Summary of Miami mine production, 1911-70

Commodity and source	Date	Ore treated, tons	Recovery, pounds
COPPER			
Underground mining period:			
High-grade ore............	1911-25............	25,900,498	719,511,040
Low-grade ore[1]............	1926-59............	106,984,450	1,198,186,918
Mixed ore[2] (sulfide and oxide)..................	1934-43............	9,591,299	248,793,924
Total (48 years).......	1911-59............	142,476,247	2,166,491,882
Leaching-operations period:			
Copper solutions[3].........	1943-70............	20,917,442	268,618,203
Burch precipitates........	1948-52, 1954, 1955	9,575	1,535,904
Total (29 years).......	1942-70............	NAp	270,154,107
Total copper production all sources (59 years)	1911-70	NAp	2,436,645,989
MOLYBDENUM			
Byproduct-operations period (21 years): Molybdenum recovered from copper concentrates[4].............	1938-59............	NAp	7,964,853

NAp--Not applicable.

[1]Complete figures are not available. Copper production figures exclude ore treated in 1933-34 and 1941-42, and copper recovered in 1932 and 1941-42. Small amounts of silver and gold have also been obtained from the ores, but the amount is not available. The mine was closed in 1933-34.

[2]Figures published in the Annual Report of the Miami Copper Co. for 1943, page 4, include data for 1941-42.

[3]Principally from inplace leaching of mined-out areas.

[4]Molybdenum figures not published for 1938 (when production started), 1939, and 1941-43. Molybdenum sulfide was recovered from copper ores and converted to molybdic oxide.

Sources: Arizona Department of Mineral Resources. Copper Industry Statistics (1).
Miami Copper Co. Annual Reports 1911-59 (11).

Ore was obtained by underground mining from 1909 until 1959, when the operation was completely converted to inplace leaching of the fractured ore remaining in the block-caved mining areas. Underground mining methods used by the company included (1) top slicing after extraction by square setting the peaks of ore under the cap rock, (2) shrinkage stoping with sublevel caving of pillars, (3) undercut caving with hand tramming, (4) high-column block caving, and (5) inplace leaching of the mined-out areas. High-grade ore was mined by the first three methods from 1910 to 1925, when the operation was converted to block caving to economically obtain the low-grade and mixed oxide and sulfide ores. Inplace leaching, begun in 1941, became the mining method when conventional underground mining was stopped in 1959.

Production from 1910 to 1959 has been classified by Hardwick (7) as follows:

	Tons of ore	Quality
1910-25	24,200,000	High grade
1926-54	101,000,000	Low grade
1936-43	9,800,000	Mixed ore
1954-59	18,000,000	Low grade
Total	153,000,000	

Mining methods, 1910-59	Tons of ore
Square set and top slicing	4,500,000
Shrinkage stoping with sublevel caving	2,200,000
Undercut caving and hand tramming	15,400,000
Block caving	130,900,000

These ore production figures do not agree with those obtained from the Miami Copper Co. annual reports, perhaps because of different sources of information, differences in definition of grade of ores, and rounding, and because data for 1941 and 1942 still remain as classified information.

By 1958, underground mining methods had caused surface subsidence over the Miami mine area extending some 3,400 feet north-south, about 2,600 feet east-west, and over 400 feet deep. The adjacent Inspiration open pit operation covered an area of some 3,000 by 1,500 feet at the Live Oak pit and 2,500 by 2,000 feet at the Thornton pit.

Reserves.--Estimated reserves as they appeared in the company annual reports from 1909 to 1957 are shown in table A-3. In the early days, mining, milling, and general costs were recorded in the annual reports; these costs are shown in table A-3. The costs, when studied with the history of the mine, illustrate the development and depletion of ore reserves. The year 1925 was a particularly significant date when the high-grade reserves were almost depleted and the conversion to the high-column method of block caving allowed larger tonnages of lower grade ore to be mined at reduced costs. Reserve figures were recalculated at that time, incorporating the low-grade material then made economically profitable by the lower mining and milling costs.

Current reserves figures for the leaching operations are not available. Drilling and underground exploration on the Miami East project continues to date (1973).

TABLE A-3. - Ore reserves and mining and milling costs at the Miami mine for selected years[1] [2]

Date	Type of ore	Estimated reserves, tons	Average grade percent copper, total	Percent soluble copper	Mining, per ton ore	Mining, per pound copper	Milling, per ton ore	Milling, per pound copper	General, per ton ore	General,[3] per pound copper	Total, per ton ore	Total, per pound copper
1909...	High grade............	14,000,000	2.75	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1910...	.....do...............	18,000,000	2.58	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1911...	.....do...............	18,232,000	2.58	NAp	$1.213	$0.035	$0.627	$0.018	$0.171	$0.005	$2.011	$0.058
1912...	High grade............	20,800,000	2.48	NAp	1.203	.038	.659	.021	.180	.006	2.042	.065
	Low grade.............	17,200,000	1.21	NAp								
1913...	High grade............	20,300,000	2.45	NAp	1.603	.052	.572	.018	.290	.009	2.465	.079
	Low grade.............	17,200,000	1.21	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1914...	High-grade sulfide.....	19,500,000	2.00	NAp	1.188	.039	.499	.016	.272	.009	1.959	.065
	Low-grade sulfide......	17,000,000	1.21	NAp								
1915...	High-grade sulfide.....	18,140,000	2.40	NAp	1.016	.032	.579	.019	.283	.009	1.878	.060
	Low-grade sulfide......	17,000,000	1.21	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1916...	High-grade sulfide.....	16,400,000	2.40	NAp	1.119	.039	.589	.020	.229	.008	1.937	.066
	Low-grade sulfide......	28,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1917...	High-grade sulfide.....	14,760,000	2.40	NAp	1.268	.047	.691	.026	.325	.012	2.285	.085
	Low-grade sulfide......	28,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1918...	High-grade sulfide.....	12,570,000	2.38	NAp	1.360	.050	.722	.026	.335	.012	2.418	.088
	Low-grade sulfide......	36,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1919...	High-grade sulfide.....	11,054,349	2.38	NAp	1.540	.048	.924	.029	.450	.014	2.915	.091
	Low-grade sulfide......	36,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1920...	High-grade sulfide.....	10,723,410	2.26	NAp	1.301	.042	.827	.027	.393	.013	2.522	.082
	Low-grade sulfide......	36,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1921...	High-grade sulfide.....	8,899,834	2.26	NAp	1.149	.040	.705	.025	.383	.013	2.238	.078
	Low-grade sulfide......	36,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1922...	High-grade sulfide.....	6,756,187	2.26	NAp	1.113	.036	.644	.021	.300	.010	2.057	.067
	Low-grade sulfide......	36,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1923...	High-grade sulfide.....	5,106,643	2.08	NAp	1.231	.045	.621	.023	.289	.011	2.141	.079
	Low-grade sulfide......	36,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1924...	High-grade sulfide.....	4,034,505	2.08	NAp	1.129	.046	.637	.026	.270	.011	2.037	.082
	Low-grade sulfide......	36,000,000	1.06	NAp								
	Mixed oxide and sulfide	6,000,000	2.00	NAp								
1925[4]..	Sulfide...............	67,917,514	1.01	NAp	.853	.048	.572	.032	.195	.011	1.620	.091
	Mixed.................	7,000,000	1.83	NAp								
1926...	Sulfide...............	84,586,743	.93	0.10	.371	.025	.491	.034	.149	.010	1.010	.069
	Mixed.................	7,000,000	1.83	1.34								
1927...	Sulfide...............	99,609,480	.88	.09	.416	.032	.413	.032	.165	.013	.994	.077
	Mixed.................	7,000,000	1.83	1.34								
1928...	Sulfide...............	95,397,981	.88	.09	.407	.036	.382	.034	.165	.015	.954	.084
	Mixed.................	7,000,000	1.83	1.34								
1929...	Sulfide...............	90,391,980	.88	.09	.423	.036	.359	.031	.152	.013	.934	.080
	Mixed.................	7,000,000	1.83	1.34								
1930...	Sulfide...............	84,276,787	.88	.09	.396	.036	.297	.027	.139	.013	.832	.076
	Mixed.................	7,000,000	1.83	1.34								

See footnotes at end of table.

TABLE A-3. - Ore reserves and mining and milling costs at the Miami mine for selected years[1] [2]--Continued

Date	Type of ore	Estimated reserves, tons	Average grade percent copper, total	Percent soluble copper	Mining, per ton ore	Mining, per pound copper	Milling, per ton ore	Milling, per pound copper	General, per ton ore	General,[3] per pound copper	Total, per ton ore	Total, per pound copper
1931...	Sulfide................	79,884,325	.88	.09	.357	.031	.277	.024	.183	.160	.818	.072
	Mixed..................	7,000,000	1.83	1.34								
1932...	Sulfide................	78,527,502	.88	.09	.340	.031	.251	.023	.143	.013	.734	.066
	Mixed..................	6,911,678	1.83	1.34								
1933...	Mine closed............	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1934...	.....do................	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1935...	Sulfide................	78,480,288	.88	.09	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Mixed..................	6,144,581	1.69	.93								
1936...	Sulfide................	77,064,141	.88	.09	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Mixed..................	4,656,523	1.55	.92								
1937...	Sulfide................	72,237,128	.88	.09	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Mixed..................	3,048,413	1.41	.98								
1938...	Sulfide................	70,655,771	.88	.09	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Mixed..................	3,170,702	1.65	.81								
1939...	Sulfide................	67,520,321	.89	.09	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Mixed..................	2,306,877	1.61	.88								
1940...	Sulfide................	63,119,451	.90	.09	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Mixed..................	1,496,612	1.59	.90								
1941-44	NA.....................	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1945...	Sulfide................	39,109,637	.86	.07	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1946...	.....do................	36,794,000	.87	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1947...	.....do................	32,281,000	.88	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1948...	.....do................	27,279,009	.89	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1949...	.....do................	23,004,854	.83	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1950...	Sulfide................	18,609,263	.78									
	Estimated recovery.....	16,000,000										
1951...	Ore....................	12,000,000	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1952...	Low grade..............	23,000,000	.5	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Total ore..............	31,500,000										
1953...	Low grade..............	23,000,000	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
	Total ore..............	27,600,000										
1954...	Total ore..............	24,600,000	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1955...	Total minable ore[5].....	16,000,000	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1956...	.....do................	12,840,000	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1957...	Total ore..............	3,470,000	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1958...	NA.....................	NA	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
1959[5]..	(6)[6].....................	(5)[6]	(5)[6]	(6)[6]	(5)[6]	(6)[6]	(5)[6]	(5)[6]	(6)[6]	(5)[6]	(5)[6]	(5)[6]

NA--Not available.
NAp--Not applicable.
[1]Ore reserves, 1909-58; mine mill, and general costs, 1912-32 as reported in the company annual reports. No costs were reported after 1932.
[2]Costs were based on the smelter returns showing the amount of refined copper obtained from concentrates on board the cars at Miami, Ariz.
[3]General expenses included taxes, general expense, mine office, general surface, research, engineers, manager and superintendent salaries. Not included were freight (to smelter, refining, or market), smelting, refining, legal, New York office, and marketing expenses.
[4]Ore reserves were recalculated to include a lower grade ore previously not considered profitable to mine. New "high column" method of undercut block caving was introduced, and costs were dramatically reduced the last 3 months of the year.
[5]Reserves were revised downward when metallurgical recovery of nonsulfide content of low-grade ores did not meet expectations.
[6]Underground mine closed. Estimates not available for determining reserves where copper was recovered by inplace leaching of areas previously mined by block caving methods.

Source: Miami Copper Co. Annual Reports, 1909-58 (11).

History

1873, Sept. 19	Maricopa Book of Mines shows the Globe Ledge claim, recorded on September 19, 1873, was located by Regan, Robert Anderson, David Anderson, Isaac Copeland, William Sampson, William Long, and T. Irwin (6).
1875	The Globe mining district was organized in November 1875. The Globe claim, the first in the newly formed district, was located in 1875 on the Old Dominion vein. The old Globe mine, which included the Globe and Globe Ledge claims, later became part of the Old Dominion mine, one of the major producers of the Globe district (17-18).
1880's	The mines in the Globe district were first worked for silver; in 1881, copper became an important commodity. Prospectors worked much of the entire area, including that now known as the Miami district, some 6 miles west of Globe. Among the early mines of the Miami area were the Black Copper group, described in 1887 (26), and the Continental mine, also located in the 1880's (26). Hardwick reported the Keystone and Live Oak claims were located in 1887; the mines later became part of Inspiration Copper Consolidated Co. (7). Stevens (22, v. 5, p. 748) said the Live Oak Mining & Smelting Co. property was discovered in 1888 and closed in 1898. At that time chrysocolla and some malachite were the the principal ore minerals evident (18, 22).
1890's	In the mid-1890's, there was a general revival of prospecting in the Miami area. Development work was in progress at the Black Warrior, Black Copper, and Continental mines, and later at the Live Oak and Keystone mines (18). In the late 1890's John B. "Black Jack" Newman located 13 claims in the Miami area near the Inspiration claim owned by John D. Coplen and obtained controlling interest in several neighboring claims. He later called all the claims the Oats-Newman group (12).
1905	In the Copper Handbook, 1905, Miami Copper Co. was reported to have been organized with $500,000 capitalized at $5 per share. The address was Globe, Ariz. No other information was given; the Copper Handbook, 1906, reported a letter to the company was returned unclaimed (22, v. 5-6).
1906, Dec.	Ransome (19) reported F. C. Alsdorf procured options on most of the claims now included in the Miami group during 1905-1906; in December 1906, those properties were transferred to General Development Co. This company was controlled by the Lewisohns of New York City.

1906, late	According to Parsons (<u>12</u>), J. Park Channing, a consulting engineer for General Development Co., and F. C. Alsdorf, a mining engineer, visited the Miami-Inspiration area in November. On this visit, Channing and Alsdorf negotiated with Newman, Oats, and others in a long evening session, finally reaching an agreement. Channing obtained an option to acquire the claims for $150,000 in cash and a 1/20 interest in any company formed to equip and operate the property. No payment on the option was required for 6 months, when the first $50,000 fell due.
1907, Jan.	Under the direction of J. Parke Channing, General Development Co. began exploration by sinking a shaft first on the Captain claim at a point where the rock was stained a brilliant green. No ore was found in this shaft. Some 850 feet farther east, a second shaft was put down on the Red Rock claim (<u>17</u>).
1907, Apr.	Ore was found in the Red Rock shaft at 220-foot depth (<u>17</u>).
1907, June	The first payment on the option was made to Black Jack Newman and associates (<u>12</u>).
1907, Nov. 30	Miami Copper Co. was organized. Property totaled approximately 300 acres, including 22 claims of about 200 acres and 100 acres in mill and smelter sites. Water rights were held on Pinal Creek. The company was formed under the laws of Delaware, with a capitalization of $3 million and shares at $5 par. The stock, a total of 600,000 shares, was controlled through ownership of one-half of the stock by General Development Co. By November 1909, authorized capitalization was increased to $3,500,000 and by August 1910 to $4 million at $5 per share for a total of 800,000 shares; $3,319,000 worth of stock was issued. Of the last increase, 60,000 shares were offered to stockholders at $18 per share; 88,236 shares were set aside for conversion of an issue of $1,500,000 worth of 10-year 6 percent gold bonds. Ultimately, the bonds were converted, and 747,116 shares were outstanding (<u>12</u>, <u>22</u>). Parsons (<u>12</u>) described the approximate investment of new capital required to finance the mine and plant construction to treat over 2,500 tpd of ore and recover about 2.7 million pounds per month:

Purchase price (cash)	$150,000
Initial exploration	100,000
Mine development and exploration	4,500,000
Total	4,750,000

1908	The experimental mill was built; equipment included one Nissen stamp, two Johnson vanners, and five Wilfley tables (<u>22</u>). A survey was made for extending the Gila Valley, Globe and Northern Railroad Co. railway from Globe to Miami (<u>22</u>).
1908, Oct. 15	Mine development or construction by this date included the following: Red Rock shaft, three compartments, 720 feet deep, with

levels at 270 feet, 370 feet, and 470 feet, and plats cut for levels at 570 feet and 670 feet. Ore was intersected at 220 feet, and tenor increased at depth; however, at 570 feet, the ore in the schist averaged only 1.5 percent copper. The Red Springs shaft, some 2,150 feet northwest of the Red Rock shaft, was about 348 feet deep and also in ore. The first shaft, the Captain, a three-compartment shaft, had been temporarily stopped at the 220-foot depth. To protect against caving, extraction was planned through the No. 4 shaft, the main working shaft spotted outside the proven ore zone (22).

1909 The four-compartment No. 4 shaft was started outside the known limits of the ore. By yearend, the shaft was down 450 feet (11, 22).

1909, Apr. Grading was started for construction of mill (11).

1909, Oct. The standard-gage railway was completed from Globe to the Miami mine (11).

1909, end Housing construction was underway (11).

1910 Early in the year in an area not reached by underground work, exploration was started with three Star churn drills. The surface was laid out in 200-foot squares and drilled at each corner. Seven holes were drilled by April, all in ore ranging from 75 to 210 feet in thickness with an average grade of over 2 percent (11).

The first ore was mined and stockpiled. Mining methods used were square setting, top slicing, and shrinkage stoping with sublevel caving of the pillars (11).

Construction of the central powerplant was completed to provide compressed air and power for mine and mill. Compressed air was supplied at 90 pounds' initial pressure; power generated consisted of 25-cycle alternating current at 6,600 volts. The capacity of the compressor was 4,000 cubic feet. The power was obtained from two 1,000-kilowatt generators run by four-cylinder triple-expansion engines using steam at 185 pounds' pressure with 100° F superheat. Fuel was oil supplied from a 500,000-gallon storage tank; however, the plant was also designed to use coal (11, 22).

Construction of one pumping plant was completed, to bring 1 million gallons of water per day from the Old Dominion mine in Globe. Three 10-inch wells each produced 500,000 gallons per day. Water was also transferred from Pinal Creek by 25,000 feet of 14-inch-diameter pipe (11, 22).

By the end of the year, 29 of 32 churn drill holes were completed; drilling totaled 16,991 feet. Cuttings from 14 holes showed a

"good grade" of sulfide ore; the remaining holes carried less than 1.5 percent copper, which was temporarily disregarded as ore. Exploration drilling and underground work showed 58 mineral-bearing acres, approximately 15 acres of which were considered too low grade. Underground work included samples taken at 5-foot intervals throughout the workings. At this time some 164 acres remained to be tested (11, 22).

1910-11	By the end of 1910, the No. 4 four-compartment working shaft was sunk to a depth of 710 feet. The shaft had a 110-foot steel head-frame, with sheave journals 90 feet above the collar of the shaft. Eighteen-inch timber used in the shaft was Louisiana longleaf yellow pine, preserved by 12 pounds of creosote per cubic foot. By 1911, main drifts were opened at 220-, 245-, 270-, 295-, 320-, and 420-foot depths. The extraction levels were at 320-, 420-, 470-, and 570-foot depths; the main extraction levels were at the 420- and the 570-foot levels. Ore was hauled in twenty 2-1/2-ton cars by six 1/2-ton electric locomotives (22).
1911, Mar. 15	The first section of the mill started operation with a gravity-concentration process. By April, four sections were on-stream, and the first shipment was made to the smelter. By the end of 1911, five sections were completed, and production was increased to 2,500 tpd. Concentrates were shipped to Cananea Consolidated Copper Co. (also referred to as Green Consolidated Copper Co.) at La Cananea, Sonora, Mex. (11). Between 1906 and 1911, almost $10 million had been expended in preparation for production (24).
1911, end	Eight new holes were churn-drilled in unexplored areas adjacent to the ore body. Most of the ore found was low grade (11).
1912, Feb.	All six sections of mill were completed; by yearend 3,000 tpd was being processed (11).
1912, end	An additional 21 churn drill holes were put down from the surface to an average 612-foot depth. Some drill holes encountered high-grade ore, and others a belt of 1.2 percent copper material 500 feet wide, lying to the north of the Northwest ore body. Nine vertical diamond-drill holes put down below the 570-foot level intersected sulfide ore averaging 2.5 percent copper (11).
1913	Because of caving of capping in the Northwest ore body in April 1913, mining costs increased from $1.20 in 1912 to $1.60 per ton. This ore body was being used by the company to experiment on the size of shrinkage stopes and pillars (11).
1913, late fall	The first experimental flotation unit (minerals-separation type) was installed in one section of concentration plant. By August 1914, the flotation unit was replaced with Callow pneumatic flotation equipment to treat slimes. Changes also included regrinding the middling; plans were made to expand mill capacity to 4,000 tpd (8, 25).

1914	Production increased to 3,500 tpd because of changes begun during the planned expansion (11).
1914, June	Underground ventilation was adopted and a 60,000-cubic-foot-capacity pressure fan was installed; in 1915 a suction-type fan was installed on the surface above the Captain ore body (11).
1915, Apr. 9	The company began to ship concentrates to the new smelter of International Smelting Co. at Miami (25).
1915, July	All mill sections had been equipped with Callow pneumatic flotation units to treat the slime portion of the ore. In addition, iron balls were gradually substituted for pebbles in the grinding mills. By introducing other changes, including Dorr classifiers, a more efficient fine-grinding operation was developed from 1915 to 1919 (8, 11).
1916	A 100-tpd experimental plant was erected to test changes required to bring the plant up to 6,000 tpd (11).
	By yearend concentrator production increased to 6,000 tpd (11).
1917	With only two sections completed, remodeling of the mill halted because of lack of powerplant capacity.
	Late in the year work commenced on a four-compartment, concrete-lined, new main hoisting shaft, the No. 5. The shaft was completed to 963 feet by 1919; the new electric hoist for handling men and supplies went into operation by February 1920. Ore production from this shaft awaited the arrival and installation of the new ore hoist (11).
1918	By 1918, approximately 36 million tons of low-grade ore averaging 1.06 percent copper had been outlined. Churn drilling on this low-grade ore area had been resumed about 1915 and continued till 1919, with underground exploration supplementing the drilling (11).
1918, Dec. 31	Gravity-concentration machines had been discarded and replaced by flotation equipment in five of the six mill sections (11).
1919	Because of depressed copper-market conditions, ore treated averaged 4,705 tpd, 75 percent of capacity. In 1918, the ore treated at the mill averaged 5,900 tpd (11).
1920	The entire mine was converted to a system of mining by shrinkage stoping with undercutting and caving of pillars. Until 1919, this method was employed only for the Captain ore body; the Main ore body was mined by the top-slicing method (25).
	The Captain ore body was reportedly exhausted in midyear (25).

	During the general shutdown of major copper mines, Miami operations continued at 75 percent of normal capacity; concentrate was stockpiled at International Smelter (<u>11</u>, <u>17</u>).
1921, June 20	A new mining and crushing plant was established at the No. 5 shaft. Mining operations had caused the surface to settle, and the No. 4 shaft had to be abandoned as a hoisting shaft (<u>11</u>).
1923	Territory east of the Miami fault was explored during the year; ore of "good grade" was penetrated by diamond drills, but the tonnage was not estimated. In 1924, it was reported that while good ore was encountered, no body of merchantable ore large enough to warrant exploitation was found. Exploration in this area continued in 1925 and was discontinued without adding anything to the reserves (<u>11</u>).
	High-grade mixed oxide and sulfide ore reserves were sufficient for only 2 years' operation; the decision was made to expand operations in order to mine low-grade reserves (<u>17</u>). The low-grade ore body had an area of 50 acres and an average thickness of 206 feet, and was overlain by an average thickness of 320 feet of barren capping (<u>10</u>).
1923-25	Mill capacity was increased from 6,800 to 10,000 tpd in order to begin treating the low-grade sulfide ore. The increase was expected to reduce the cost per ton for mining, milling, and general expense, even though the yield per ton would be less. Remodeling resulted in increased tonnage and considerably finer grinding, decreasing the tailings loss of sulfide copper (<u>11</u>).
1924	Development mining of low-grade copper ore body was begun (<u>17</u>).
1925	The new "high-column" method of undercut block caving and controlled ore drawing commenced. The ore body was mined in individual stopes or blocks, originally 150 by 300 feet in cross section and 300 feet or more high. During the latter part of the year, production of copper came solely from treatment of low-grade ore. Average mining costs dropped from $1.12 in 1924 to $0.437 per ton during the last 3 months of 1925 (<u>7</u>, <u>11</u>).
1925, Oct. 1	The expansion of the concentrator was completed; the plant was operated at capacity, 10,000 tpd (<u>8</u>).
1925, end	Results of the last 3 months' work on the low-grade ore and the indicated lower mining costs allowed a recalculation of ore reserves based on older data obtained from drill holes, mining, and development work (<u>11</u>).
1926	A full year of mining low-grade ore was completed; mining costs averaged $0.371 per ton (<u>11</u>).

1927	Additional equipment installed in the concentrate retreatment plant raised the grade of concentrate produced from 27.96 percent copper in 1926 to 34.26 percent in 1927, with an increase in concentration ratio from 37.22 to 51.58 tons of ore to 1 ton of concentrate (11).
1927-28	Plant capacity was gradually increased from 10,000 to 12,000 tpd. Milling costs decreased from $0.637 in 1924 to $0.382 per ton in 1928 (11).
1928, fall	A decision was made to increase plant capacity from 12,000 to 17,000 tpd. Plans included construction of a modern powerplant (8).
1928, Dec.	Concentrator expansion was started (11).
1929	Capital expenditures to increase plant capacity from 6,600 to 17,500 tpd were noted by Parsons (12):

Mining plant	$371,810
Concentrating plant	2,303,618
Powerplant	1,263,606
Total	3,939,034

1929, Oct. 1	The mine and mill were placed on a 17,000-tpd basis (11).
1930	Mixed oxide-sulfide ore was tested in the laboratory (11).
1930, Apr.-fall	The price of copper decreased from 18 cents to 9-1/2 cents per pound (11). Average price for the year was listed by Engineering and Mining Journal at 12.982 cents per pound.
1930, Aug.	An inclined ventilation shaft, the No. 6, collared in August, had been put down 760 feet by yearend. The shaft was completed in 1931 (11).
1931	A 250-tpd experimental beneficiation plant to treat mixed oxide-sulfide ore was put into operation June 18, 1931. The process, known as the leach-precipitation-flotation (L-P-F) beneficiation method, was developed by F. W. Maclennan and Harmon Keyes (11).
	Owing to the below-normal copper consumption and the low price of copper metal, the property was operated at reduced capacity. The reduced tonnage allowed finer grinding, resulting in the highest grade concentrate, 40.88 percent copper, produced to this date from the low-grade ore body (11).

1932, Feb.-Aug.	A plant costing $313,089 was constructed to treat 3,000 tpd of oxide-sulfide ore. The plant was operated intermittently until February 8, 1933, when the entire property was shut down (11).
1932, May 15	The mine was closed owing to the decline in copper price; during 1932, the price averaged 5.555 cents per pound with a low of 4.8 cents per pound (11).
1933	Although the property remained closed, an experimental run of the new leaching plant was made (11).
1934	Production resumed on a small scale. Copper price for 1934 averaged 8.4 cents per pound (11). Mixed ore, not amenable to treatment in the sulfide ore plant, was treated in the new plant, by the L-P-F method developed by the company between 1929 and 1934 (2, 11).
1935	Plant operation was curtailed (11).
1936	Mixed ore treated in the L-P-F plant increased from 3,000 to 4,500 tpd (11). The L-P-F plant capacity, initially reported as 4,800 tpd, was rapidly increased to 6,000 tpd (2). During the shutdown begun in 1932, the sulfide ore already broken in the stopes became oxidized; the ore had to be temporarily abandoned because it was not amenable to treatment in the sulfide plant. New stopes started in July 1936 were brought into production in early 1937 (11).
1937	Another inclined shaft, the No. 7, was put down to replace the abandoned No. 3 shaft. The shaft, started in April, was sunk 1,653 feet by yearend and completed to a depth of 1,680 feet in 1938 (11).
1938	A molybdenum plant was constructed for recovery of molybdenite from copper sulfide concentrates and put in operation August 1938 (11).
1939	Leaching equipment was added to the molybdenum plant to increase the extraction of molybdenite (11).
1940, May 1	Miami Copper Co. acquired properties of Old Dominion Co. near Globe to provide water for the Miami plant. Beginning in 1937, a water shortage was partly alleviated by drilling additional wells and by installing a 180-foot dewatering tank in 1939. Beginning in March 1940, however, operations were gradually reduced because of the diminished water supply; by July the plant was down to 72 percent of capacity. The Old Dominion Co., a subsidiary of Phelps Dodge Corp., was purchased on May 1, 1940; by August the additional water was made available at the Miami mine. The cost of the property and of the mine renovation was about $290,000. Other

properties of the Old Dominion Co. acquired at that time included the Continental group of claims at the head of Webster Gulch near Miami (13).

1941 Facilities were installed for leaching and precipitating copper from the capping and from the broken ore remaining in abandoned sections of the Miami mine (11).

1942, Jan. Copper production by leaching the copper-bearing material in the abandoned sections of mine commenced and has continued to the present (1972) (11).

1943, May 7 The mixed-ore body was completely mined out; operations in this area were discontinued, and the mixed-ore beneficiation plant was dismantled (11). Production from the mixed-ore body from July 1934 to May 1943 totaled 9,591,299 tons of ore assaying 1.443 percent total copper, of which 0.864 percent was oxide copper and 0.579 percent was sulfide copper. Copper production amounted to 248,793,924 pounds in the form of concentrates, assaying 49.786 percent copper. Mill recovery was 91.8 percent of the copper contained in ore (11).

Production was then obtained exclusively from the sulfide ore body--93 percent from the 1,000-foot level and 7 percent from the Captain area on the 720-foot level (11).

1944 Mining of sulfide ore in the Captain ore body, resumed in 1943, was completed in 1944; shaft No. 8, put down to service this area, was abandoned. The section was made available for inplace leaching (11).

1944, Apr. Work was started to move offices and residences several miles to a new location on flat land, away from the projected subsidence area. The new site was provided with roads, sewers, electric power, natural gas, and water for irrigation and domestic use. By yearend, 13 houses were relocated (11).

1945 Inplace leaching of sulfide copper minerals in abandoned parts of the mine required a solvent containing sulfuric acid and ferric sulfate. In 1945, a pilot plant, one-fourth the size of a commercial unit, was designed and constructed to produce the solvent. The plant was then incorporated into the full-scale facility (11).

1945, Dec. 31 Dividends paid by Miami Copper Co. up to December 31, 1945, totaled about $39,461,904 (11).

1946 Premium Price Plan payments for wartime copper production ceased for Miami Copper Co. on November 1, 1946. These payments were made on copper produced from its operating mines in excess of production quotas. The ceiling price of 12 cents per pound for electrolytic copper delivered to points in New England was established

August 1941 by the Office of Price Administration and remained in effect until June 3, 1946, when it was increased to 14-3/8 cents per pound. Simultaneously, the "A" copper premium under the Premium Price Plan was reduced from 5 to 2-5/8 cents per pound. On November 10, 1946, the celing prices of copper were discontinued; the market price for domestic electrolytic copper rose to 17-1/2 cents per pound. On November 23, 1946, the price increased to 19-1/2 cents per pound where it remained until yearend (11).

1949 An initial report was made of copper being recovered by lime treatment of copper-bearing water pumped from the Burch water basin. The water was then used for industrial purposes (11).

1950 Churn-drill exploration beyond the Miami fault, started in 1949, was discontinued in 1950 because of unfavorable results (11).

1951, Jan. 26 A general price-freeze order set the price for most domestically produced copper at 24.5 cents per pound. The price control was removed February 1953 (11).

1952 Churn-drill exploration increased the reserves of low-grade copper ore by an estimated 23 million tons. Development of the ore body, estimated to cost $3 million, was scheduled to be completed in 1955 (11).

1953 A contract signed on February 13 with Defense Materials Procurement Agency provided that the General Services Administration would purchase 230 million pounds of copper produced from the new, low-grade, submarginal ore at a guaranteed price of 27.35 cents per pound (subject to escalation). The Government also had an option to purchase any molybdenum concentrates produced incidental to the above low-grade ores. Purchase was guaranteed at $1 per pound or the prevailing market price, whichever was greater. The company had the right to tender to the Government, and the Government was obligated to purchase all the molybdenum concentrates from the low-grade ore body that the company was unable to sell on the open market at or above $1 per pound. The contract further provided the Government with an option to purchase up to 120 million pounds of copper produced from previously proved old reserves of the Miami mine. The copper was to be sold to the Government at the lower of the following two prices: (1) The E&MJ Metal & Mineral Market price averaged during the month of the delivery to the Government, or (2) the contractor's ceiling price for domestic refined copper on the date of delivery to the Government. Both delivery prices were f.o.b. Connecticut Valley (11, 13).

Development of the low-grade (0.5 percent copper) ore body was underway. The deposit was largely below the old stopes of high-grade mixed ore in the Captain area of the mine (17).

1954 Mar.	Beginning in March and gradually expanding during the year, production was obtained from the low-grade ore body in the Captain area (11). The Government exercised its option to purchase up to 120 million pounds of copper produced from the reserves remaining in the old section of the mine (11).
1955	Dilution of the mixed ore by overlying oxidized capping to a greater extent than expected resulted in an increase in the amount of oxide to sulfide copper in the mill feed. Some copper contained in the malachite, azurite, and cuprite minerals was recovered by flotation; however, the copper contained in the dominant copper-bearing mineral, chrysocolla, could not be recovered. The mixed ore assayed 0.4 percent sulfide-copper and 0.5 percent nonsulfide-copper. Selective mining was, therefore, initiated in the low-grade section of the mine to improve copper recovery and to lower costs (2, 11). Mining schedules were revised to eliminate 3.5 million tons of the nonsulfide material from mining reserves. The remaining copper in the unmined reserves was scheduled for recovery by inplace leaching at the conclusion of the block-cave mining operations (11).
1955, Aug. 31	The Government contract for sale of copper from the low-grade section of mine was terminated (11).
1956	Early in the year, the Government contract covering the high-grade section of the mine was completed when the balance of the required 120 million pounds of copper had been produced (11).
	Research during the year suggested recovery could be improved by treatment of high oxide ores using the L-P-F circuit developed in the 1935-42 period. Treatment involved leaching the crushed ore with acid, precipitation of copper on shredded iron, and flotation of copper precipitates for recovery of copper content. In late 1956, an allotment to install the L-P-F circuit in the concentrator was requested (2, 11).
	Expansion and modernization of the precipitation plant was begun (11).
1957, early	Construction of the second section of the new precipitation plant was begun and by yearend was 55 percent complete; underground pumping facilities were 47 percent complete (11).
1957, Mar.	One section of the new precipitation plant placed was in operation for inplace leaching (11).
1957, Apr. 16	Operation of the new L-P-F circuit was begun and conducted successfully with only normal interruptions until March 31, 1958, when the low price of copper forced shutdown of the mill (2). The average price of copper dropped from about 42 cents per pound in 1956 to 26 cents per pound in 1958.

1958, Jan. 1	Minable ore reserves were estimated to be 3,470,000 tons on January 1, 1958. The estimates of reserves were revised downward when the decision was made to curtail the underground operation early in 1958 (11).
1958, Apr. 1	The production of high-grade oxide ore was discontinued, eliminating the need to operate the L-P-F circuit; capacity of the mining operation was reduced from 12,000 to 6,000 tpd (11).
1958, late	The precipitation plant was completed and additional sump capacity and pumps were installed on the 1,000-foot level of the Miami mine (11).
1959	New pumps and a pipeline network required for the in situ leach operation were added to the solution distribution system on surface (11). In midyear underground mining was discontinued. Remaining recoverable copper in the mined-out area was to be extracted by inplace leaching and precipitation (11).
1960, Feb. 29	The Board of Directors of Miami Copper Co. approved and authorized a plan for complete liquidation of the company to be submitted to the stockholders for their approval (11).
1960, June 10	"Tennessee Corp. purchased the plants, equipment, and certain other assets (including investments in subsidiary companies), and entered a lease-option agreement covering the mining properties of Miami Copper Co. subject to an interest in the ore reserves (reserved in-ore payment) which was sold by that company for $15 million. The lease-option agreement provides that such reserved in-ore payment, together with an amount equivalent to 6 percent per annum on the unliquidated balance thereof, may be satisfied by delivery of 27 percent of the copper concentrates and 27 percent of a major portion of the copper precipitates produced from the Miami properties (or cash equivalent to the market value of such copper) until the reserved in-ore payment is extinguished, or until Tennessee may exercise its option to purchase the mining properties, or otherwise terminate the agreement. If the option to purchase is exercised, the price shall be the balance of the reserved in-ore payment. Upon final settlement of the reserved in-ore payment, Tennessee will take full title to the remaining ore reserves, subject to a substantially smaller periodic in-ore (royalty) payment" (23, 1960, p. 10).
1963, June	Tennessee Corp. merged with Cities Service Co. (3).
1969, early	Miami Copper Co. began mining a low-grade area along the Miami-Inspiration properties boundary by open pit methods. The material, assaying 0.78 percent total copper (0.59 percent oxide copper and

0.19 percent sulfide copper), was transferred into the subsidence area created by the block-caving operation. The project, involving the transfer of 1,348,172 tons into a 200,000-square-foot area averaging 135 feet thick, was to have been completed in September. Leaching solutions applied to the surface area percolated through the mineralized material; the solutions were collected on the 1,000-foot level of the mine (5, 14).

1969, Apr. Cities Service announced discovery of mineralization in Miami East area (15).

1970 The Inspiration Consolidated Copper Co. annual report for 1970, page 8, reported that Cities Service announced discovery of an ore body east of the fault that terminated the eastern extremity of the Miami-Inspiration deposit. Inspiration drilled on property adjacent to Miami Copper from August 1969 into 1970. Inspiration's five drill holes ranged in depth from 3,300 to 5,500 feet. The first four, as they progressively probed east of the fault system to greater depths, showed minor but increasing copper mineralization. The fifth hole, beginning at 4,800 feet, showed a 300-foot mineralized column with an average copper content of slightly over 1 percent, underlain by more than 300 feet of lower grade material (9).

1970, Jan. Ten drill holes were completed in the downfaulted segment of the Miami-Inspiration deposit. On the basis of information from eight drill holes, the Miami East ore body was estimated to range from 2,460 to 3,800 feet in depth and from 150 to 645 feet in thickness. Drill-hole assays of the mineralized zone averaged 1.35 percent copper. Engineering studies were underway for a projected 4,000-foot shaft at the discovery site to provide access for underground drilling, bulk sampling, and detailed evaluation of the deposit. Shaft sinking was estimated to require approximately 1-1/2 years (15).

1970, Apr. 9 Boyles Brothers Drilling Co. of Salt Lake City was awarded a contract to deepen the old Miami No. 5 shaft for exploration of the deposit. The shaft was scheduled to be deepened from its present depth of 1,120 feet to 3,520 feet; completion was expected about February 1972. Van Dyke-Dail Co. and Hagen Construction Co. made preparatory changes in the shaft. Existing hoist facilities were to be retained, and leaching was to continue in the Miami mine (16).

1973, Mar. Deepening of the old Miami shaft was to be completed in 1973, and development of the mine was to follow. Production from the high-grade ore body was to begin late 1974 and to reach 2,000 tpd by 1978. Ore will be processed in existing company facilities.

1973, Apr. The Miami East ore body is 3,000 feet long by 1,200 feet wide with a maximum thickness of 400 feet; the top of the deposit is at a

depth of 2,500 feet. Located 2,000 feet east of the Miami ore body, Miami East dips north and east with a maximum pitch of 34° (21).

REFERENCES

1. Arizona Department of Mineral Resources. Copper Industry; Statistics for (year) Compared With Other Years, Arizona, United States and World (title varies). Phoenix, Ariz., annual publications 1960 through 1970.

2. Bean, J. J. The Leach-Precipitation-Flotation Method of Concentration at Miami Copper Co. Colo. School Mines Quarterly, v. 56, No. 3, 1961, pp. 263-281.

3. Cities Service Co. Annual Report, 1963-72.

4. Fletcher, J. B. Ground Movement and Subsidence From Block-Caving at Miami Mine. Trans. AIME, v. 217, 1960, pp. 413-422.

5. _____. In-Place Leaching, Miami Mine, Miami, Arizona. Pres. to Soc. Min. Eng., AIME, New York, Feb. 26-Mar. 4, 1971, AIME Preprint 71-AS-40, 13 pp.

6. Granger, B. H. Arizona Place Names. University of Arizona Press, Tuscon, Ariz., 1960, p. 103.

7. Hardwick, W. R. Block-Caving Copper Mining Methods and Costs at the Miami Mine, Gila County, Ariz. BuMines IC 8271, 1965, 96 pp.

8. Hunt, H. D. Milling Methods and Costs at the Concentrator of the Miami Copper Co., Miami, Ariz. BuMines IC 6573, 1932, 26 pp.

9. Inspiration Consolidated Copper Co. Annual Report, 1970, p. 8.

10. Maclennan, F. W. Miami Copper Co. Method of Mining Low-Grade Orebody. Trans. AIME, v. 91, 1930, pp. 39-86.

11. Miami Copper Co. Annual Reports, 1909-59.

12. Parsons, A. B. The Porphyry Coppers. American Institute of Mining and Metallurgical Engineers, New York, 1933, pp. 161-183.

13. _____. The Porphyry Coppers in 1956. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1957, pp. 96-109.

14. Pay Dirt. Miami Copper Checking Possible Ore Discovery. No. 358, Apr. 28, 1969, p. 28.

15. _____. Miami Copper Studying Two Interesting Prospects. No. 367, Jan. 26, 1970, pp. 1, 6.

16. _____. Miami Copper To Deepen Shaft for Exploration. No. 370, Apr. 27, 1970, p. 3.

17. Peterson, N. P. Geology and Ore Deposits of the Globe-Miami District, Arizona. U.S. Geol. Survey Prof. Paper 342, 1962, 151 pp.

18. Ransome, F. L. Geology of the Globe Copper District, Arizona. U.S. Geol. Survey, Prof. Paper 12, 1903, pp. 114-118, 134.

19. _____. The Copper Deposits of Ray and Miami, Arizona. U.S. Geol. Survey Prof. Paper 115, 1919, p. 92.

20. Rubley, G. R. Miami-Inspiration District. Ch. in Some Arizona Ore Deposits. Ariz. BuMines Geol. Series 12, Bull. 145, 1938, pp. 66-72.

21. Skillings, D. N., Jr. Pinto Valley Project. Skillings' Min. Rev., v. 62, No. 17, Apr. 28, 1973, p. 16.

22. Stevens, H. J. The Copper Handbook. Horace J. Stevens, Houghton, Mich., v. 4, 1904, 778 pp.; v. 5, 1905; v. 6, 1906, 1116 pp.; v. 7, 1907, 1228 pp.; v. 8, 1908, 1500 pp.; v. 10, 1910-11, 1902 pp.

23. Tennessee Corp. Annual Reports, 1960-62.

24. Tuck, F. J. Stories of Arizona Copper Mines. Arizona Dept. Mineral Resources, Phoenix, Ariz., 1957, pp. 9-22.

25. Weed, W. H. The Mines Handbook. Stevens' Copper Handbook Co., New York, v. 12, 1916, 1699 pp.; Mines Handbook Co., Tuckahoe, N.Y., v. 16, 1925, 2350 pp. (replaced Copper Handbook listed as reference 22).

26. Wendt, A. F. The Copper-Ores of the Southwest. Trans. AIME, v. 15, 1886-87, pp. 25-77.

APPENDIX B.--HISTORICAL DEVELOPMENT OF THE CASTLE DOME PROPERTY

Ownership.--In 1972, the Castle Dome property was owned by Cities Service Co. Castle Dome Copper Co., Inc., a subsidiary of Miami Copper Co., acquired the properties of Pinto Valley Co. in 1941. In 1960 Miami Copper Co. merged with Tennessee Corp., and in 1963 Tennessee Corp. became a subsidiary of Cities Service Corp.

Location (fig. A-1).--The Castle Dome area is 5 miles west of Miami in the Globe-Miami district, Gila County, Ariz. The mine is on the south flank of Porphyry Mountain in unsurveyed secs 20, 21, 28, and 29, T 1 N, R 14 E, in the western part of the Globe quadrangle as mapped by the Geological Survey in 1901. The operation was accessible by a branch road 4 miles long that connected with U.S. Highway 70, 5 miles west of Miami (fig. A-1).

Climate.--The annual precipitation is about 20 inches, mainly from cloudbursts during July and August. Light snowfall commonly occurs in the Castle Dome area between December and February.

Topography.--The terrain is fairly rugged and irregular. In 1951, the top bench near the crest of Porphyry Mountain was mapped as 4,750 feet; the lowermost bench was shown as 4,265 feet. The top of Red (South) Hill is 4,229 feet.

Geology (5-6).[1] --The mineralization in the Castle Dome area covers almost 1 square mile. The principal host rock of the Castle Dome ore body is the Lost Gulch quartz monzonite. Except for a large block of an intrusive west of the Gold Gulch fault and separated from the main mass, the Lost Gulch quartz monzonite is confined to a prominent horst structure which trends north-northwesterly through the central part of the Castle Dome area. The most prominent structure within the mine is the northeast-trending Dome fault zone which divides the ore body into two parts, separated by irregular bodies of waste consisting of leached or unenriched protore related to the fault zone.

Hypogene mineralization--consisting mainly of pyrite, chalcopyrite, and small amounts of molybdenite, sphalerite, and galena--is confined principally to the quartz monzonite and granite porphyry. Hypogene mineralization in the granite porphyry appears to be weak. Pyrite and chalcopyrite are disseminated or occur in narrow, closely spaced quartz veins. Veins containing massive chalcopyrite occur near diabase sills in the southern part of the quartz monzonite. Molybdenite, widely distributed in many parts of the mine, has averaged 0.01 to 0.02 percent MoS_2. Sphalerite and galena are present in a few scattered veins, particularly within the Dome fault system; gold and silver occur only in very small amounts. Mineralization shows a distinct zoning pattern.

Supergene enrichment, not nearly as extensive as in the Miami-Inspiration deposit, plays an important part in the formation of the ore body and is

[1]Underlined numbers in parentheses refer to items in the list of references at the end of this appendix.

clearly related to the present topography. The tenor of the ore was increased by supergene enrichment especially in the southern part of the ore body where chalcocite and covellite were formed as a replacement of chalcopyrite. Chalcocite is the most abundant supergene sulfide mineral. Covellite was formed by the oxidation of chalcocite, or to a lesser degree by the replacement of chalcopyrite. In a few places in the oxidized zone, small masses of cuprite were formed by oxidation of chalcocite; cuprite was further altered to form malachite and azurite. Small amounts of malachite are present throughout the capping; turquoise is fairly widespread in the chalcocite zone and in the leached capping. The most common occurrence of oxidized minerals is in and near the diabase sills.

Localization of copper mineralization is due to the effect of (1) zoning in the hypogene mineralization, (2) the richer copper metallization associated with the fine-grained diabase sills intruded into the quartz monzonite, and (3) supergene enrichment, especially in the southern part of the ore body.

In 1951, Peterson and others (6) estimated that the ore body, measured on the long axis, ranged from 2,000 feet on the 4,330-foot level to 3,800 feet on the 4,085-foot level. Leached capping over the ore body ranged from a few feet to a maximum of 250 feet and averaged about 80 feet. Complete leaching rarely extended more than 150 feet below the surface, and generally contained less than 0.1 percent copper. The transition from waste to ore containing 0.4 percent copper usually occurred in less than 15 feet.

Production (1-2, 4-5).--From 1943 to 1953 Miami Copper Co. mined the Castle Dome ore on Porphyry Mountain by open pit. In 1953, the open pit operation was terminated, and dump leaching began and continued to 1970, the last year production was reported. Table B-1 shows the open pit production and copper, gold, and silver recovered; table B-2 shows the amount of precipitate copper recovered from dump leaching.

The following data, which cover the life of the Castle Dome property from June 1943 to December 1953 when the open pit mine was shut down, were published by Parsons (4):

Ore mined and milled..................tons..	41,442,000
Stripping removed......................do...	48,484,000
Grade of ore...............percent copper..	0.725
Tailing................................do...	0.087
Recovery as concentrate...........percent..	88.2
Copper produced.......................tons..	257,195
Copper produced, approximate value..........	$106,000,000
Gold and silver produced, value.............	$777,000

In addition to the metals recovered, the deposit was an important source of turquoise. The molybdenite and small occurrences of galena and sphalerite were not recovered.

TABLE B-1. - Copper, gold, and silver produced from the Castle Dome mine, 1943-53

Year	Ore, tons	Copper, pounds	Gold, ounces	Silver, ounces
1943............	1,714,205	18,020,066	1,871	95,975
1944............	4,107,975	49,743,367		
1945............	4,183,769	53,324,969	1,306	86,851
1946............	4,102,566	56,590,107	1,571	84,210
1947............	3,890,627	52,840,237	658	73,653
1948............	3,890,126	49,585,565	288	37,557
1949............	3,744,922	46,306,057	396	45,233
1950............	3,690,465	44,795,706	254	33,350
1951............	3,864,250	49,712,786	992	36,694
1952............	4,300,937	52,655,859	504	24,707
1953............	3,952,775	40,815,598	451	35,908
Total......	41,442,617	514,390,317	8,291	554,138

Source: Peterson, N. P. Geology and Ore Deposits of the Globe-Miami District, Arizona. U.S. Geol. Survey Prof. Paper 342, 1962, p. 88 (5).

TABLE B-2. - Copper recovered from precipitates from the Castle Dome mine, 1953-71

Year	Precipitate copper recovered, pounds	Year	Precipitate copper recovered, pounds
1953..............	162,113	1963..............	5,513,538
1954..............	815,190	1964..............	4,882,984
1955..............	2,229,277	1965..............	4,059,881
1956..............	5,233,462	1966..............	4,121,736
1957..............	4,990,745	1967..............	2,122,387
1958..............	5,264,116	1968..............	2,430,667
1959..............	4,902,751	1969..............	1,831,291
1960..............	5,306,988	1970..............	933,400
1961..............	5,397,242	1971..............	-
1962..............	5,505,398		

Sources: Arizona Department of Mineral Resources. Copper Industry Statistics (1).
Miami Copper Co. Annual Reports, 1953-58 (2).

Reserves.--Castle Dome ceased open pit mining in 1953. No reserves for the leaching operation were published.

History.--Mining history in the Globe-Miami area began with the location of the Globe claim in the Globe area 6 miles east of the Miami area. The importance of the deposits west of the Globe area was recognized about 1881, resulting in the erection of a small copper furnace on Western Pass road, 6 miles west of Globe (6).

1881 (ca.) The first mining location in the Castle Dome-Miami area was the Continental claim. Other locations followed on the south flank of Jewel Hill and along Gold Gulch; however, names of claims and actual dates are unknown (6).

1896 Considerable development work was underway at the Continental mine about 3,000 feet northeast of Porphyry Mountain (6).

1899 Old Dominion Co. of Globe, Ariz., purchased the Continental mine (6).

1901-02 (ca.) Ransome (8), in 1903, reported no shipments had been made from the Continental mine at the time of his visit. Workings consisted of three tunnels with several hundred feet of drifts and crosscuts and some small shafts. Two levels--the fourth and fifth--were below the third tunnel level, which is the main adit. Total depth reached was about 350 feet. Peterson (6) noted the host rock was in a small finger of quartz monzonite projecting from the east margin of the intrusive, bounded on the north, east, and south by a diabase intrusive. Sulfide ore in the main vein was generally low grade, 2 to 3 percent copper, but there was an occasional 20 percent copper. This vein, oxidized 100 feet below the surface, contained rich ore of cuprite, malachite, azurite, and native silver. Sporadic production from 1906 to 1936 was reported. An enriched zone had an estimated 5.2 percent copper, 0.058 ounces of gold, and 3.4 ounces of silver per ton. After 1936, copper grade decreased to an average of 0.74 percent; gold and silver increased to 0.15 ounce and 4.45 ounces per ton, respectively (6, 8).

1905-10 Many claims were located on Porphyry Mountain and throughout the Cactus mineralized area on Pinto Creek, about 2 miles south of Porphyry Mountain. During this time most of the claims were acquired by Arizona National Copper Co., the Pinto Copper Mining Co., and the Cactus Development Co. (6).

1906 Castle Dome Development Co., with a mine office in Globe, was reported sinking a 4- by 8-foot shaft. The exact location of the shaft was not given. By November 1908, operations at the site ceased; stockholders were notified the $30,000 spent on "development work" was to be refunded (10).

Pinto Creek Mining and Smelting Co. planned to expand its mill to 100 tons by fall of 1906. The company had been organized December 11, 1896, in Arizona; capitalization increased in 1906 to $1.25 million, shares $1 par. Property was 21 claims including the Yo Tambien claim and the Manito claim in the Pinto Creek area. The Yo Tambien had a 570-foot shaft and a 900-foot connecting tunnel; the Manito had a 79-foot shaft and three tunnels totaling 1,500 feet. In December 1905, D. L. Ricketts and J. C. Erman had tested the ore and suggested expanding the 30-ton concentrator to 100 tons (10).

1906, Feb. 1	Arizona National Copper Co. was organized in Arizona with a capitalization of $3 million, shares $10 par, and bonds of $300,000 at 5 percent. Property included 14 claims, 1 millsite, and 100 acres of timber on Pinto Creek (10).
1906, Nov.	Pinto Creek Copper Mining Co. was organized November 21, 1906, in Arizona, with a capitalization of $1 million, shares $1 par. Land consisted of nine claims near the Arizona and Globe Standard property on Pinto Creek (10).
1908, Apr. 3	Castle Dome Copper Co. was organized under laws of Arizona and reorganized April 3, 1908, with a capitalization of $600,000, shares $10 par. Lands included 12 claims (about 240 acres) 17 miles west of Globe near the Continental mine of the Old Dominion, on the eastern side of Pinto Creek, "with the deepest workings of 300 feet in schist-diorite" (10).
1908, Oct.	Cactus Development Co. was organized in Minnesota with a capitalization of $500,000, shares $1 par. Property consisting of 33 claims on Pinto Creek 4 miles west of Miami was held under bonds and leases aggregating $415,000. Old workings by former owners consisted of two short tunnels and two two-compartment shafts (10).
1909, June	Castle Dome Mining Co. was organized in Arizona with capitalization of $1.5 million, shares $5 par assessable, $1 paid. The company was previously known as Castle Dome Copper Co. Property was reported to be 13 claims (260 acres) on the eastern side of Pinto Creek, about 1-1/2 miles northeast of the Cactus mine, and near the Continental mine "of the Black Warrior, including Continental Springs." Workings included the 200-foot-deep Virginia shaft. Mine was idle in 1910-11 (10).
1909, Aug.	Cactus Development Co., reorganized as Cactus Copper Co., was idle from 1910 through 1911. Cactus Copper Co. had been organized in Minnesota with a capitalization of $5 million, shares $5 par, 2,828,345 issued. The company was controlled by Lycoming Co., which owned about 40 percent of the shares. Cactus Copper Co. had an interest in the Pinto Creek Copper Mining Co. Original lands of Cactus Copper Co. covered about 1,400 acres and included 9 claims held under bond from the Pinto Creek Copper Mining Co.; 14 claims, a 15-acre millsite, and 100 acres of timber land held by the Arizona National Copper Co.; and 42 claims, known as the Upper group, added in 1910. Cactus Copper Co. acquired a 51-percent interest in Pinto Creek Copper Mining Co. in consideration for sinking the Hamilton shaft 500 feet. The Cactus mine in the Pinto Creek area had two shafts to depths of 530 and 541 feet; about 1 mile of lateral openings plus considerable churn drilling had been done. The surface showed indications of mineralization; however, the ore was found to be spotty and not commercial. Work was abandoned and bonds on the property were surrendered about October 1910 (10).

1910 (ca.) Development work by Arizona National Copper Co. at the Pinto Creek property included 50- and 75-foot shafts and 195-, 250-, and 300-foot tunnels. Lands were under option to Cactus Development Co. (which was succeeded by Cactus Copper Co.). Cactus Copper Co. reportedly relinquished its bonds on the lands late in 1910. The deposit, described as contact veins between the schist and granite, averaged 14 inches wide and was traced 785 feet. High-grade oxidized ores in the vein contained chrysocolla and native copper, with some chalcopyrite and bornite. The 80-foot "ledge" of decomposed schist contained slight copper sulfide mineralization (10).

1910-11 (ca.) Mortgage on Pinto Creek Mining & Smelting Co. was foreclosed (10).

1913, Feb. 11 Inspiration Extension Copper Co. was organized in Delaware with capitalization of $1 million, shares $5 par, $80,000 issued. Property at this time was nine unpatented claims (145 acres) partially surrounded by Inspiration Consolidated Copper Co. land. Development of this property included a 90-foot shaft put down in September 1913 (9, 11).

1915 Castle Dome Development Co. was incorporated 1915 in Maine with a capitalization of $3 million, shares $5 par (11). Peterson (6) noted that holdings at the time of incorporation consisted of eight patented claims on Porphyry Mountain and a 97-percent interest in the Inspiration Extension Copper Co.

1916 Castle Dome Development Co. had a bond and lease on the Inspiration Extension Copper Co. property, and on April 16 began work on a tunnel "in anticipation of opening a low-grade porphyry copper" deposit. By 1916 Inspiration Extension Copper Co. was reported to have an additional 29 unpatented claims (about 500 acres) on Porphyry Mountain (11).

1917 Castle Dome Development Co. owned 94 percent of outstanding capital of the Inspiration Extension Copper Co. (11).

1918-19 Exploration by Castle Dome Development Co. included drilling seven churn-drill holes (6).

1920 Castle Dome Development Co. property reportedly comprised 34 unpatented claims in the Castle Dome group; the company owned 97 percent of outstanding capital and had a bond and lease on Inspiration Extension Copper Co. and owned four adjacent claims 5 miles west of Inspiration Consolidated Copper Co. Exploration by churn drilling and a tunnel showed a diabase intrusion. Ore on the property was estimated to contain from 1 to 3 percent copper (11, v. 14).

Arizona National Copper Co. had been mortgaged to Susquehanna Trust and Safe Deposit Co. for a loan of $250,000. Susquehanna foreclosed on the mortgage and obtained title to the property in 1920 (6).

1921, Apr. 7 — Pinto Valley Co. was incorporated in Delaware with a capitalization of $500,000, shares $1 par. The company was organized to reassemble the defunct Arizona National Copper Co. and the defunct Cactus Development Co. (which had been previously reorganized as Cactus Copper Co.) (11).

1921 — Pinto Valley Co. leased and optioned Arizona National Copper Co. lands from Susquehanna Trust and Safe Deposit Co. for 3 years. The option was exercised and Pinto Valley Co. acquired the assets of Arizona National Copper Co., which included Pinto Creek Copper Co. and Cactus Copper Co. (6).

1922 — Weed (11, v. 16) reported the Castle Dome Development Co. by this time had eight tunnels and 4,500 feet of workings on Porphyry Mountain. Churn drilling was reported to show a diabase intrusion 20 feet wide in granite. An estimated 10 million tons of ore on the main property was reported to range from 1 to 2-1/2 percent copper and to average 1.4 percent copper (11).

1924, Feb. — Pinto Valley Co. increased capitalization to $4 million and acquired the assets of Castle Dome Development Co. through a merger. The merger required an exchange of 600,000 shares of Castle Dome Development Co. and payment of $15,000 cash (6). The property consisted of 1,700 acres and included 65 claims (22 patented), 34 adjacent claims that were controlled through subsidiaries, and options on 3 other claims. The property was known as the Castle Dome Development group and included claims formerly held by Cactus Consolidated Mining Co., Arizona National Copper Co., and Pinto Copper Mining Co. (11). The 37 claims on Porphyry Mountain became known as the Castle Dome division, and the Pinto Valley Co. property on Pinto Creek was known as the Cactus division (6). Weed (11, v. 16) reported the Castle Dome disseminated copper ore body had been explored for 3,000 feet and showed a 1-1/2 percent copper sulfide ore with a thickness of 100 feet; in the Pinto Valley group, the ore was estimated to contain upwards of 100,000 tons of 4-1/2 percent carbonate ore in fissure veins and "large bodies of disseminated ore."

1924 — Four more churn-drill holes were put down on the Castle Dome division. On the basis of ore indicated in the 11 churn-drill holes driven to this time, a metallurgist was employed to conduct tests for the leaching of copper from the Castle Dome (6).

1926 — A small pilot plant for metallurgical tests was set up on the property (6).

Castle Dome division was estimated to have reserves of 40 million tons of 0.75 percent copper. The Castle Dome group had been developed by 5 tunnels and explored by 11 churn-drill holes; the Pinto Valley property had 3 shafts and 25 churn-drill holes (3, 7).

1926-28 Two more churn-drill holes were drilled on Porphyry Mountain (6).

1929 Additional exploration included a diamond-drill hole put down to a depth of 1,085 feet. A contract was made with Inspiration Consolidated Copper Co. to treat 3,000 tpd of Castle Dome ore in an 8-year period. Reserves at this time were estimated to be 9 million tons of ore containing 1.27 percent copper and 20 million tons containing 0.8 percent copper. The proposed mining method was underground block caving similar to that used at the Miami mine. Encountering considerable difficulties during the Depression years, Pinto Valley Co. was unable to finance the venture (6).

1940, May 1 Miami Copper Co. purchased the Old Dominion Co. and its holdings from Phelps Dodge Corp. The properties acquired were in the Globe-Miami district and included the Continental mine, held by Old Dominion since 1899. Part of the Continental claims covered the east end of the Castle Dome ore body. Production from the Continental mine, 1906 to 1941, has been reported to be 34,000 tons of ore containing about 2 million pounds of copper, 134,000 ounces of silver, and 3,600 ounces of gold; 14,300 tons of ore was mined from 1906 to 1908 (5-6).

1940, July Exploration drilling commenced in the Castle Dome area, including the newly acquired Continental claims (2, 6).

1940, fall Miami Copper Co. obtained an option on the Castle Dome group of claims from the Pinto Valley Co. (2, 6).

1941, Nov. Miami Copper Co. exercised its option for the Castle Dome group and adjoining mining properties. These properties, including the Continental group, were deeded to the Castle Dome Copper Co., Inc., a wholly owned subsidiary of Miami Copper Co. (2, 6).

1941, late Castle Dome Copper Co., Inc., and the U.S. Government through the the Defense Plant Corp. (DPC), a subsidiary of the Reconstruction Finance Corp. (RFC), entered into an agreement for the developing of the Castle Dome ore body and construction of the concentrating plant and necessary facilities and services. The concentrating plant was reported to be owned by and under lease from DPC. The Miami Copper Co. noted in its annual report that when the treatment plant was completed and the operation on-stream, they would be required to supply additional working capital needed by the Castle Dome Copper Co., Inc., for the operation (2, 4). Parsons (4) noted the Government supplied $9 million to finance stripping of the overburden and building the plant.

1941, end	Churn drilling of 61 holes had been completed by yearend as part of a campaign to determine the extent and grade of the copper deposit (2).
1942, Jan.	Construction of the treatment plant and other facilities commenced. W. A. Bechtel Co. was the contractor for removing 14 million tons of overburden and for building the concentrator (4).
1943, Apr. 19	Castle Dome Copper Co. took over the mine excavation operations from the contractor (2).
1943, June 10	Mine production and treatment facilities were brought on-stream in a record 17 months. The ore body was stripped and mined with 40-foot-high benches.
1943, Dec. 31	By yearend 13 of the benches had been worked to a vertical depth of 550 feet (2). The mill was brought up to a designed capacity of 10,000 tpd (2).
1944	Exploration drilling consisted of 11 holes averaging 254 feet (2).
	Late in the year mill capacity was increased to 12,000 tpd (2).
1945	Exploration to the northeast of the known ore body consisted of seven holes drilled to an average depth of 385 feet, but results were negative. Exploration to the southwest of the ore body commenced; 10 holes were drilled (2).
1946	Exploration to the southwest of the Castle Dome ore body was completed. The 43 churn-drill holes, totaling 13,508 feet, developed 6,127,000 tons of ore with a copper content of 0.704 percent of which 0.05 percent was oxide. Estimates indicated that higher mining costs were anticipated at the new ore body (2).
1948, Jan. 1	An agreement under which mill and other facilities were owned by the RFC but leased by Castle Dome Copper Co., Inc., was amended effective January 1, 1948, to permit mining the southwest ore body. Parsons (4) noted that the investment by the Government increased from \$9 million to \$13.8 million. Preparations were made to mine ore underlying Red Hill to the southwest of the main ore body (2, 4).
1949	Stripping was completed preparatory to mining of the Red Hill section (2).
1953, Dec. 4	Castle Dome completed open pit mining operations on December 4; dismantling and moving of the plant and equipment to the Copper Cities project of Miami Copper Co. began 2 days later. Some precipitate copper was recovered during the year (2).

1953, Dec. 31	Lease with RFC was terminated.
1953-70	Leaching of dumps was continued to 1970 (2). In 1957-58 installation of pipelines and pumping system to distribute water on top of old dumps was completed for improving the leaching operations (2).
1970	Production from the property was last reported in this year (1).

REFERENCES

1. Arizona Department of Mineral Resources. Copper Industry; Statistics for (year) Compared With Other Years, Arizona, United States and World (title varies). Phoenix, Ariz., annual publications 1959 through 1971.

2. Miami Copper Co. Annual Reports, 1940-59.

3. Neale, W. G. The Mines Handbook. Mines Handbook Co., Inc., New York, v. 17, 1926, 2129 pp. (replaced Copper Handbook listed as reference 10).

4. Parsons, A. B. The Porphyry Coppers in 1956. American Institute Mining, Metallurgical, and Petroleum Engineers, New York, 1957, pp. 96-109.

5. Peterson, N. P. Geology and Ore Deposits of the Globe-Miami District, Arizona. U.S. Geol. Survey Prof. Paper 342, 1962, 151 pp.

6. Peterson, N. P., C. M. Gilbert, and G. L. Quick. Geology and Ore Deposits of Castle Dome Area, Gila County, Arizona. U.S. Geol. Survey Bull. 971, 1951, 134 pp.

7. Rand, L. H., and E. B. Sturgis. The Mines Handbook. Mines Information Bureau, Inc., Suffern, New York, v. 18, pt. 1, 1931, 2026 pp. (replaced Copper Handbook listed as reference 10).

8. Ransome, F. L. Geology of the Globe Copper District, Arizona. U.S. Geol. Survey Prof. Paper 12, 1903, 168 pp.

9. _____. Copper Deposits of Ray and Miami, Arizona. U.S. Geol. Survey Prof. Paper 115, 1919, 192 pp.

10. Stevens, H. J. The Copper Handbook. Horace J. Stevens, Houghton, Mich., v. 6, 1906, 1116 pp.; v. 7, 1907, 1228 pp.; v. 8, 1908, 1500 pp.; v. 9, 1909, 1628 pp.; v. 10, 1910-11, 1902 pp.

11. Weed, W. H. The Copper Handbook. W. H. Weed, Houghton, Mich., v. 11, 1912-13, 1413 pp.

12. _____. The Mines Handbook. Stevens' Copper Handbook Co., New York, v. 12, 1916, 1699 pp.; W. H. Weed, New York, v. 13, 1918, 1896 pp.; v. 14, 1920, 1992 pp.; Mines Handbook Co., Tuckahoe, N.Y., v. 15, 1922, 2248 pp.; v. 16, 1925, 2350 pp. (replaced Copper Handbook listed as reference 10).

APPENDIX C.--HISTORICAL DEVELOPMENT OF THE COPPER CITIES PROPERTY

Ownership.--In 1972, the Copper Cities property was owned by Cities Service Co. Miami Copper Co. owned the property from 1942 to 1960 when the company was acquired by Tennessee Corp. In 1963 Tennessee Corp. was merged with Cities Service Co.

Location (fig. A-1).--The mine is located in unsurveyed sec 12, T 1 N, R 14 E, and sec 7, T 1 N, R 15 E, on the south flank of Sleeping Beauty Peak, 3-1/2 miles north of Miami, in the Globe-Miami mining district, Gila County, Ariz.

Climate.--Annual precipitation, occurring mainly in July, August, December, January, and February, is about 20 inches. Mean annual snowfall is about 3.6 inches. Temperatures range from 14° to 110° F.

Topography.--The original surface altitude ranged from 4,250 feet on the highest hill to 3,870 feet in the bed of the Tinhorn Wash at the southern limits of the mine.

Geology (2, 4, 10, 13).[1]--Host rocks for the Copper Cities deposit are the Lost Gulch quartz monzonite intruded by a granite porphyry. The rocks, including thin diabase dikes, are similar to the intrusives in the Castle Dome area. The oldest rock formation in the Copper Cities area is the Precambrian Pinal schist. The Lost Gulch quartz monzonite is in a horst block bounded by the Sleeping Beauty fault on the northwest side, the Ben Hur fault on the northeast side, and the Miami fault on the east side. The ore body is bounded by the Coronado fault zone on the west, the Drummond fault zone on the east, and the Sleeping Beauty fault on the north. The quartz monzonite host rock was intricately dissected by joints and fractures. The copper content is greatest near the quartz monzonite-granite porphyry contact; the granite porphyry has a higher molybdenite concentration than the quartz monzonite.

Principal hypogene minerals, arranged in descending order of amount, are quartz, pyrite, chalcopyrite, and molybdenite. Chalcopyrite is the most important ore mineral; molybdenite is sparse but increases with depth. Chalcocite and covellite are the only supergene sulfide minerals in the deposit; chalcocite is the predominant mineral, and enrichment extends from 100 to 220 feet below the leached capping. In 1962, the mine limits were said to roughly delineate the chalcocite ore (10). Malachite, azurite, and turquoise are present in the ore body and in the leached capping.

In 1966, the mine was over 2,000 feet long by 1,000 feet wide in the northwest and 2,000 feet wide in the southeast. The ore ranged from 100 to 400 feet in thickness, averaging about 200 feet. Grade of ore in 1965 was 0.7 percent total copper; by 1972, Beall (2) noted the grade of the ore was 0.5 percent copper and 0.007 percent molybdenum sulfide. Leached capping ranged

[1] Underlined numbers in parentheses refer to items in the list of references at the end of this appendix.

from 20 to 120 feet in thickness, averaging 70 feet. Grade of the capping was less than 0.1 percent copper.

Production (1-2, 5, 16).--From 1954 through 1972, open pit production of copper ore totaled 66,778,118 tons; copper recovered was 357,363 tons. Dump leaching began in 1962; by 1972, 20,376 tons of copper had been obtained. Beall (2) reported 28,000 tpd of ore and waste were mined in 1972; ore production was at a rate of 14,000 tpd, averaging 0.5 percent copper and 0.007 percent MoS_2.

The concentrator, originally designed for 12,000 tpd, was transferred from the Castle Dome mine to the Copper Cities area in 1953. By 1970 the capacity had been increased to 13,500 tpd. A molybdenite circuit was installed in the concentrator in 1968; capacity was reported to be 180 tpy by 1972.

Production data for copper are shown in table C-1; no production figures are available for molybdenum.

TABLE C-1. - Copper production at Copper Cities mine, 1954-72

Year	Copper ore mined, tons	Average grade of copper, percent	Copper recovered, pounds	Dump leach copper recovered, pounds
1954	996,160	0.783	12,514,108	NAp
1955	4,004,052	.824	55,097,164	NAp
1956	4,167,147	.795	55,264,337	NAp
1957	3,482,482	.714	41,492,801	NAp
1958	2,768,390	.79	36,072,087	NAp
1959	3,060,575	NA	36,939,297	NAp
1960	3,058,372	NA	33,100,562	NAp
1961	3,137,253	NA	34,672,592	NAp
1962	3,150,952	NA	33,827,784	175,661
1963	3,149,260	NA	35,402,918	1,039,062
1964	3,163,565	NA	35,969,908	5,719,192
1965	3,200,202	NA	34,950,395	4,258,791
1966	4,353,896	NA	43,286,852	5,168,968
1967	2,429,806	NA	22,315,647	2,792,459
1968	3,359,097	NA	29,218,381	4,355,962
1969	4,644,525	NA	39,785,236	3,799,103
1970	4,970,196	NA	47,456,074	4,490,916
1971	4,629,571	NA	44,858,816	4,375,751
1972	5,052,617	NA	42,501,763	4,577,066

NA--Not available. NAp--Not applicable.

Sources: Arizona Department of Mineral Resources. Copper Industry Statistics (1).
Miami Copper Co. Annual Reports, 1954-58 (5).

Reserves.--As of January 1, 1959, ore reserves were estimated to be 29,220,000 tons with a waste-to-ore ratio of 0.26 to 1.00 (5). From initial exploration drilling, the ore body was estimated to contain 33,800,000 tons of ore with an average grade of 0.7 percent copper, based on a cutoff grade of 0.4 percent copper; waste was estimated to be 34,700,000 tons, making the ore-to-waste ratio 1 to 1.03. Drilling nine holes in 1956 resulted in increasing the reserves by 9,500,000 tons of a slightly lower grade ore (4).

History.--First mining in the Lost Gulch area was for gold and silver deposits in the Pinal Schist. The area was prospected in the 1880's, and again about 1896 (12).

1896 Girard Mining Co. began development work; later in the year, the company was reincorporated as the Lost Gulch Mining Co. The 10-stamp mill treating the ores was discontinued because of the scant water supply. The relatively high-grade gold ore was then treated in arrastras (10).

The value of mineral production from Lost Gulch in 1896 was reportedly $48,000 (12).

1909 Lost Gulch Mining Co. was reorganized as Lost Gulch United Mines Co. (10).

1912, July Louis d'Or Gold Mining Co., practically a reconstruction of the Lost Gulch United Mines Co., was organized in Arizona with a capitalization of $2 million, shares $1 par; 1,116,540 shares were issued. The property included about 19 claims consisting of 283 acres in 3 contiguous groups about 2 miles north of the mouth of Lost Gulch. Ores were in veins averaging 3 to 4 feet wide. Mines included the Badger with a 145-foot shaft and a 400-foot tunnel with ore that reportedly averaged $7 per ton in "values"; the Bonanza, with a 1,050-foot tunnel; and the Cedar Tree, with ores mainly containing argentiferous and auriferous galena, with some copper and zinc. Copper values in 1912 were reported to be inadequate to warrant treating the ore only for their recovery; furthermore, the values were considered not recoverable after the ores had been cyanided for gold (15, 18).

1913 Charles E. Hart of Baldwin Syndicate examined the gold deposits in the Lost Gulch area and observed the porphyry outcrops of Sleeping Beauty Peak. This examination led to the eventual reorganization of the Louis d'Or Gold Mining Co. In addition to 12 claims owned by the company, the Gila Monster, Bessie, and Sarah groups covering the porphyry were optioned by the company from J. W. Bennet (no exact date given) (10).

1915, July Louis d'Or Gold Mining Co. capitalization was increased to $3 million and 1,234,450 shares issued; 300,000 shares were offered for sale by the Baldwin Syndicate in April 1916 at 25 cents per share. The company was controlled by the Baldwin Syndicate of Chicago (18).

1916, Nov. 29	Louis d'Or Mining and Milling Co., a reorganization of the Louis d'Or Gold Mining Co., was incorporated in Arizona with a capitalization of $3 million at $1 par, and 1,168,195 shares were issued. Assets in May 1917 were noted to be $35,000 (18).
1917	Churn drilling commenced in 1917 and continued through 1922 (19, vs. 14-15).
1921	Louis d'Or Mining and Milling Co. increased capitalization to $40 million, $10 par, 2,400,000 shares were issued and held in escrow to January 1, 1922. Property was reported to be 33 claims and fractions on 500 acres; a fairly uniform ore zone 400 feet thick averaging 1.15 percent copper reportedly underlay 180 acres (19, v. 15).
1922	Louis d'Or Mining and Milling Co. exploration up to the end of 1922 consisted of 12 drill holes totaling nearly 9,000 feet, several shafts and tunnels including the 1,050-foot Bonanza tunnel, a two-compartment shaft 362 feet deep by May 1922, a 125-foot shaft, and a 65-foot shaft (19, v. 16).
1923 (ca.)	Louis d'Or Mining and Milling Co. acquired all assets of Inspiration-Miami Copper Co. and Inspiration-Miami Extension Copper Co. The Inspiration-Miami Copper Co. capitalization had been $10 million, $1 par; 6 million shares were outstanding. Property of Inspiration-Miami Copper comprised several detached groups (77 claims) adjoining the Inspiration-Miami Extension, 3 miles west of Burch, a station on the Arizona Eastern Railroad. The Kleinfelder group of 30 claims was considered the most promising. The Inspiration-Miami Extension Copper Co. capitalization had been $2 million, $1 par; 1,200,000 shares were outstanding. This company held five patented claims believed to be an extension of the Louis d'Or ore body. Inspiration-Miami and Inspiration-Miami Extension companies had been owned by the same interests (7, 19).
1926	Louis d'Or Mining and Milling Co. properties, comprising a total of about 2,800 acres, included the following: 65 claims (30 patented) on 1,041 half acres owned by the company; 77 claims purchased from Inspiration-Miami Copper Co.; 5 patented claims purchased from Inspiration-Miami Extension Co. The company estimated 150 million tons of ore ranging from 1 to 1.5 percent copper on the basis of 12 drill holes. However, the large capitalization had drawn only $3 million, which was used to acquire the property, forcing the company to issue notes to secure funds for development. A reorganization was contemplated. Plans had been formulated to complete the shaft to 800 feet deep, to construct a 12,000-tpd concentrator, and to provide railway, water, power, and other facilities at a cost of $8 million (7).

1928, July 17	Louis d'Or Mining and Milling Co. assets were sold to satisfy notes (11). In 1928, the "noteholders protective committee" entered into an agreement with Pinto Valley Co., then exploring at Castle Dome and Pinto Valley areas, whereby Pinto Valley advanced funds to the committee for purchase of the Louis d'Or property at a bankruptcy sale (10).
1929	Porphyry Reserve Copper Co. was organized early in the year to operate the property formerly owned by Louis d'Or Mining and Milling Co. In late 1929 Pinto Valley Co. was reported to have taken the property under option. Lessees were said to have shipped copper ore from the workings about 1931 (11).
1929-39	Thirteen test holes were drilled on the old Inspiration-Miami Copper Co. properties. In the Tinhorn Wash east of Sleeping Beauty Peak, 350,000 pounds of copper was recovered from stream gravel cemented by copper carbonates and silicates (10).
1934-42	Porphyry Reserve Copper Co. shipped intermittently from 1934 to 1942. Bonds in amount of $500,000 were issued in 1928 or 1929, and interest payments were defaulted in 1934. Many of the lapsed unpatented claims were relocated by J. R. Heron of Globe. Bondholders foreclosed on the small group of claims that Porphyry Reserve Copper Co. still held; in 1942, these claims were purchased at a sheriff's sale by Copper Cities Mining Co., a new subsidiary of Miami Copper Co. (10).
1942	Copper Cities Mining Co. acquired most of the rest of the original claims from Heron and other locators (10).
1943, 1946-49	Exploration by churn drilling was begun on Copper Cities Mining Co. properties in 1943. Drilling was interrupted because of the manpower shortage during World War II; then in 1946 the program was resumed and continued into 1949. The basic drilling pattern was a 250-foot rectilinear grid with intermediate holes in questionable areas. By 1948, about 100 holes, averaging 600 feet deep, had been drilled to delineate the ore body. Ore reserves were estimated to be 33.8 million tons of 0.7 percent copper. Overburden was estimated to be 34.8 million tons, of which 20 million tons had to be stripped before production could begin (4-5).
1950, Nov. 15	Copper Cities Mining Co. concluded negotiations for a loan from the Reconstruction Finance Corp. (RFC). An agreement was executed covering terms and conditions under which disbursement of the loan may be requested. Moneys were to be used partly as a means of financing the cost of bringing the Copper Cities project into production (5). A loan of $7.5 million was obtained (10). The development program was planned so that after the depletion of the Castle Dome deposit, the concentrator and other facilities would be moved to prepared sites at Copper Cities and production would begin (5).

Preparation for development of the open pit operation commenced. The work was principally the construction of access roads (10).

1951	Expenditures to bring Copper Cities into production were estimated to total $12 million, the greater part to be financed at the company's option, through the loan agreement with the RFC (5). Copper Cities Mining Co. executed a purchase contract with General Services Administration which provided that the company had the right to call on the Government to purchase at the contract price of 23 cents per pound (subject to escalation) a maximum of 170 million pounds of the first 192.5 million pounds of copper produced. This stipulation was in effect if the company was unable to sell such copper for domestic use at a price equal to or higher than the contract price (5).
1951, Jan.	The Castle Dome plant and mining equipment were purchased from the RFC. Title to the Castle Dome plant and equipment passed to the company when the lease between the RFC and Castle Dome Mining Co. was terminated (5).
1951, June	Stripping of overburden was begun and building sites were prepared (5).
1951-53	Overburden removed totaled 14,101,083 tons. During 1952, concrete foundations were prepared for the concentrator, crushers, tailings thickeners, and various other structures (5).
1953, Dec. 4	Dismantling of the Castle Dome plant and transfer of the equipment to Copper Cities commenced (5-6).
1954, Aug. 2	Production was begun. The mill was brought into full production, 12,000 tpd, by November (5).
1954, Sept.	Copper Cities repaid RFC the $7.5 million borrowed under the loan agreement of November 1950. Funds came from Miami Copper Co. and from a $4.5 million bank loan (5).
1954, Dec. 31	Ore treated during the year amounted to 996,160 tons averaging 0.783 percent copper. During 1954, overburden removed was 7,257,380 tons, bringing the total amount of waste removed from 1951 through 1954 to 21,358,463 tons (5).
	A total of $13,718,000 was reported to have been expended on the Copper Cities project by this date. Miami Copper Co. provided $9,218,000, in addition to the $4.5 million bank loan (5).
1955, Dec. 31	During the first full year of production, waste removal amounted to 3,347,720 tons; ore shipped totaled 4,004,052 tons averaging 0.824 percent copper and containing 356 ounces of gold and 38,824 ounces of silver (5).

1956	Nine holes were drilled, resulting in an addition to the reserves of 9.5 million tons but of slightly lower grade (5).
1960, June	Certain assets of Miami Copper Co., including Copper Cities, were acquired by Tennessee Corp. (17, 1960).
1962	Based on estimates made from deep drilling in the previous few years, about 25 million tons of low-grade primary ore was reported underlying the ore reserves as of 1962. The ore extended the life of the Copper Cities open pit for an additional 8 years if mined continuously at the 1962 rate (17, 1962).
1962, Dec.	The copper precipitation plant at the mine site was completed and leaching operations commenced. Pyrite in the ore eliminated the necessity of adding acid to the leach solutions (13).
1963, June	Tennessee Corp. merged with Cities Service Co. (3).
1965	The Diamond H pocket of ore was dicovered near the Copper Cities mine (20).
1968	Copper Cities commenced operation of a molybdenum circuit in the concentrator. Much of the equipment had been transferred from the old Miami treatment plant. A study of 1957-66 data indicated 0.012 percent molybdenum sulfide in the heads, 0.387 percent molybdenum sulfide in the concentrates, and 0.005 percent molybdenum sulfide in the tails. The molybdenum sulfide content ore ranged from 0.007 to 0.014 percent in the ore and from 0.003 to 0.007 percent in the tails. This information led to the planning and installation of the molybdenum circuit in 1968 (16).
1970	The Diamond H pocket of ore, approximately one-sixth the size of Copper Cities mine, was scheduled for production in July. The deposit was estimated to contain 11 million tons of copper ore assaying 0.5 to 0.6 percent copper (8).
1972	The removal of ore and waste at the Copper Cities mine was 28,000 tpd, and the concentrator treated 14,000 tpd of ore. The grade of ore averaged 0.5 percent copper and 0.007 percent molybdenum sulfide (2).
1972, Feb.	Copper Cities continued an attempt to stabilize terraced tailings by establishing grass and plant growth on the dam. About 36,000 cubic yards of earth was spread over 7,200 feet on the face of the dam (9).
1973	At the present rate of production, the two ore bodies of the Copper Cities mine will be exhausted in 1975 (14).

REFERENCES

1. Arizona Department of Mineral Resources. Copper Industry; Statistics for (year) Compared With Other Years, Arizona, United States and World (title varies). Phoenix, Ariz., annual publications 1959 through 1972.

2. Beall, J. V. Copper in the United States--a Position Survey. Min. Eng., v. 25, No. 4, April 1973, pp. 35-47.

3. Cities Service Co. Annual Report, 1963.

4. Hardwick, W. R., and M. M. Stover. Open-Pit Copper Mining Methods and Practices, Copper Cities Division, Miami Copper Co., Gila County, Ariz. BuMines IC 7985, 1960, 51 pp.

5. Miami Copper Co. Annual Reports, 1942-59.

6. Miami Copper Co., Division Tennessee Corp. Description of Copper Cities Concentrator, Miami, Arizona. Pres. before Milling Div., Tucson, Ariz., Sec., AIME, Apr. 6, 1962, 24 pp.; available for consultation at Bureau of Mines Intermountain Field Operations Center, Denver Federal Center, Denver, Colo.

7. Neale, W. G. The Mines Handbook. Mines Handbook Co., Inc., New York, v. 17, 1926, 2129 pp. (replaced Copper Handbook listed as reference 15).

8. Pay Dirt. No. 372, June 22, 1970, p. 18.

9. _____. No. 392, Feb. 28, 1972, p. 32.

10. Peterson, N. P. Geology and Ore Deposits of the Globe-Miami District, Arizona. U.S. Geol. Survey Prof. Paper 342, 1962, pp. 88-95.

11. Rand, L. H., and E. B. Sturgis. The Mines Handbook. Mines Information Bureau, Inc., Suffern, New York, v. 18, pt. 1, 1931, 2026 pp. (replaced Copper Handbook listed as reference 15).

12. Ransome, F. L. Geology of the Globe Copper District, Arizona. U.S. Geol. Survey Prof. Paper 12, 1903, 168 pp.

13. Simmons, W. W., and J. E. Fowells. Geology of the Copper Cities Mine. Ch. in Geology of the Porphyry Copper Deposits; Southwestern North America. The University of Arizona Press, Tucson, Ariz., 1966, pp. 151-156.

14. Skillings, D. N., Jr. Pinto Valley Project. Skillings' Min. Rev., v. 62, No. 17, Apr. 28, 1973, p. 15.

15. Stevens, H. J. The Copper Handbook. Horace J. Stevens, Houghton, Mich., v. 6, 1906, 1116 pp.; v. 7, 1907, 1228 pp.; v. 8, 1908, 1500 pp.; v. 9, 1909, 1628 pp.; v. 10, 1910-11, 1902 pp.

16. Sutlov, A. Molybdenum and Rhenium Recovery From Porphyry Coppers. University of Concepcion, Concepcion, Chile, 1970, pp. 107-111.

17. Tennessee Corp. Annual Reports, 1960-62.

18. Weed, W. H. The Copper Handbook. W. H. Weed, Houghton, Mich., v. 11, 1912-13, 1413 pp.

19. _____. The Mines Handbook. Steven's Copper Handbook Co., New York, v. 12, 1916, 1699 pp.; W. H. Weed, New York, v. 13, 1918, 1896 pp.; v. 14, 1920, 1992 pp.; Mines Handbook Co., Tuckahoe, N.Y., v. 15, 1922, 2248 pp.; v. 16, 1925, 2350 pp. (replaced Copper Handbook listed as reference 15).

20. World Mining. Miami Coppers Diamond H Pit; 17th Copper Pit in State. V. 6, No. 9, August 1970, p. 53.

APPENDIX D.--HISTORICAL DEVELOPMENT OF THE SAN MANUEL PROPERTY

Ownership.--In 1972, the San Manuel property, including the Kalamazoo ore body, was owned by Magma Copper Co., a subsidiary of Newmont Mining Corp. It was operated by the San Manuel Division of the company.

Location (fig. D-1).--The mine, largely in secs 34 and 35, T 8 S, R 16 E, in the Old Hat mining district, Pinal County, Ariz., is 45 miles northeast of Tucson, 5 miles west of Mammoth, and 7 miles northwest of San Manuel. The concentrator, smelter, refinery, and continuous-casting rodmill are next to the town of San Manuel. Located between the Black Hills and Santa Catalina Mountains, the deposit is in the pediment that slopes northeasterly to the San Pedro River. The old Mammoth-St. Anthony or Tiger area is less than 1 mile north of the mine, and the recently acquired Kalamazoo deposit is just southwest of the San Manuel ore body.

Climate.--The winters are mild with temperatures rarely below freezing; summer temperatures frequently exceed 100° F; mean annual surface temperature is 71.7° F. Rainfall is between 10 and 13 inches per year.

Topography.--Altitude ranges from 3,450 feet on Red Hill to 3,000 feet in Tucson Wash west of shaft No. 1 and 2,400 feet at the San Pedro River. Vegetation is of a typical desert variety.

Geology (5, 10, 12-13, 16, 20, 31, 36)[1].--The principal host rocks are the Precambrian porphyritic quartz monzonite (sometimes called Oracle granite), Late Cretaceous quartz monzonite porphyry, and to a lesser extent, Late Cretaceous or early Tertiary diabase. The diabase, which intrudes the quartz monzonite and quartz monzonite porphyry, is itself intruded by rhyolite. Late Cretaceous or Tertiary andesite porphyry dikes and Tertiary rhyolite dikes in the deposit also may be slightly mineralized: The andesite porphyry with pyrite, and the rhyolite with crusts of chrysocolla or copper oxide.

Lowell (13) described the San Manuel-Kalamazoo hydrothermal mineralization as appearing to be centered in the middle of a monzonite dike swarm which was intruded in Laramide time. Ore deposition was almost equally distributed between Oracle Granite and monzonite. Following this event, the area was tilted to the northeast and eroded, and a thin chalcocite enrichment blanket formed on the exposed deposit. Further regional tilting occurred with the deposition of the volcanics and conglomerates of the Cloudburst Formation in Late Cretaceous or early Tertiary time. By Pliocene-Pleistocene time, the Gila Conglomerate was deposited on the Cloudburst erosion surface. The third stage of tilting gave the Gila Conglomerate its present inclination and brought the original vertical axis of the ore body to a 20° southwest-plunging attitude. The San Manuel fault then diagonally sliced the tilted deposit and its distinctive alteration pattern into two equally sized parts, San Manuel and Kalamazoo. The Kalamazoo, the uppermost part of the cylindrical deposit, was faulted 8,000 feet downdip in a S 55° W direction. Later,

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[1]Underlined numbers in parentheses refer to items in the list of references at the end of this appendix.

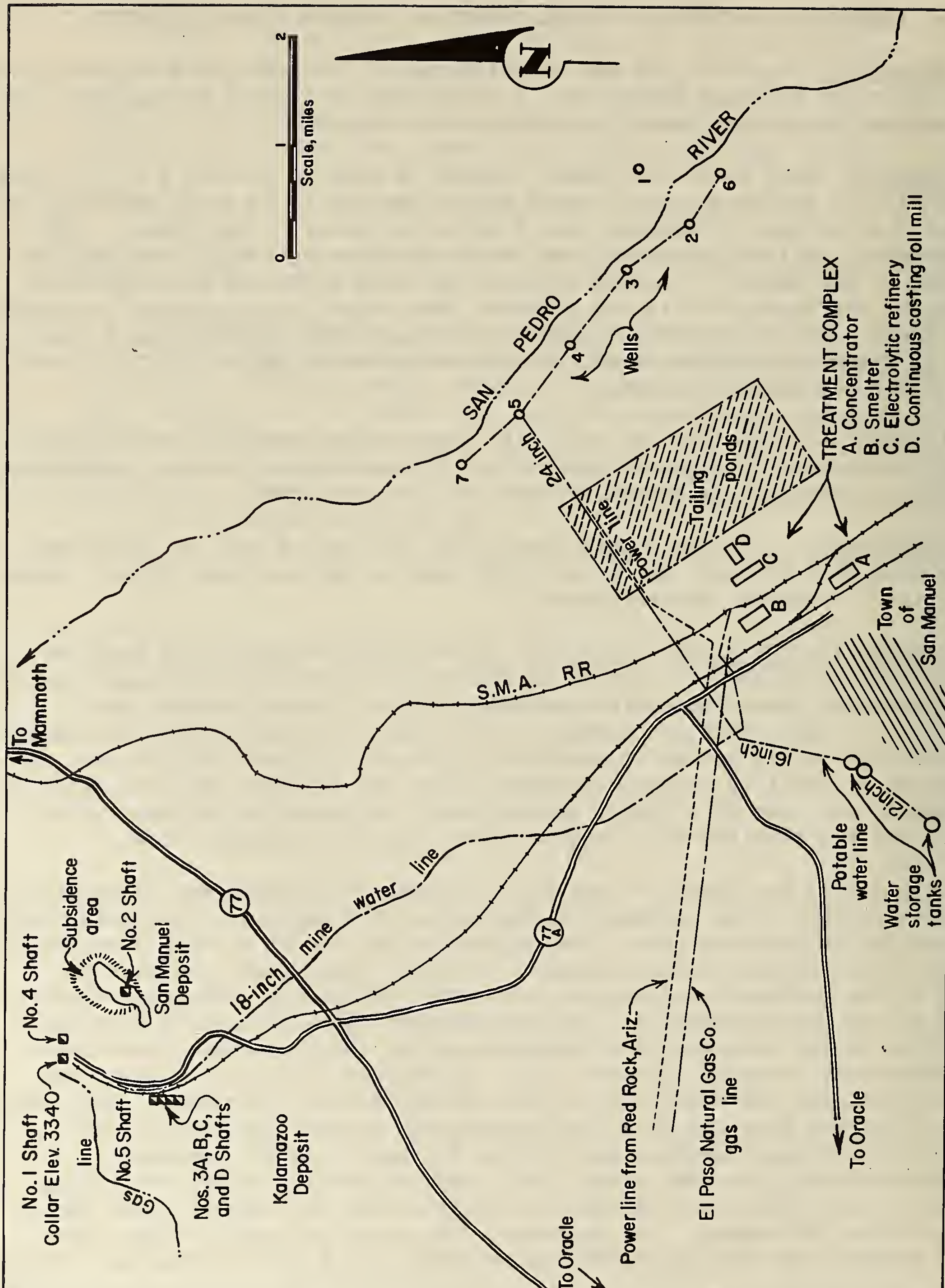

FIGURE D-1. - Map of San Manuel area, Pinal County, Ariz. (6).

steeply dipping faults offset the San Manuel part; further erosion exposed the host rocks and some of the San Manuel part of the deposit, thereby allowing further oxidation and limited chalcocite enrichment.

Ore mineralization, though slightly higher grade in the Precambrian quartz monzonite, is about equally distributed between that host rock and the Laramide quartz monzonite porphyry. The principal primary ore minerals are chalcopyrite, pyrite, some molybdenite, and rarely bornite. Chalcopyrite and pyrite are almost in equal proportions and finely disseminated throughout the ore zones, but also appear on fracture surfaces and in veinlets. Molybdenite forms a coating on fractures. Magnetite is present locally, and minor amounts of bornite are found. The chief minerals formed during oxidation were chrysocolla, chalcocite, and iron oxides. Cuprite, native copper, and black copper oxides are also found; Creasey (5), however, reports the copper carbonates are rare. According to Lowell (13), chalcocite is common in the lower part of the oxide zone and near the top of chalcopyrite mineralization in the San Manuel ore body; however, both chalcocite and oxide minerals are absent in the Kalamazoo ore body.

Buchanan (2) estimated the sulfide zone in the San Manuel ore body as ranging from 475 to 2,665 feet in depth; the base of the oxide zone is irregular and extends in depth from 400 to over 1,600 feet.

The fairly well defined zones of mineralization and alteration in the San Manuel-Kalamazoo deposit were described by Lowell (13). Because of the tilted position of the deposit, this zoning was more readily available for observation than in most other deposits. From the core outward, zones of lateral alteration include potassic, phyllic, argillic (sometimes absent), and propylitic. Ore mineralization is characteristic of certain alteration zones. The core potassic alteration zone, averaging about 2,600 feet in diameter, contains about 0.3 percent copper, almost all in a disseminated form of chalcopyrite; the pyrite-to-chalcopyrite ratio is about 1:2. An ore shell, in the potassic zone and grading into the phyllic zone, ranging from 0.5 percent to 1.0 percent copper and averaging about 600 feet thick, surrounds the low-grade core. In this ore shell the pyrite-to-chalcopyrite ratio is about 1:1; pyrite is in veinlets, and chalcopyrite is disseminated. Within the phyllic and argillic alteration zone are three types of mineralization: (1) Outer part of the ore shell; (2) adjacent to the ore shell is a marginal copper mineralization zone about 200 feet thick; values range from 0.1 to 0.5 percent copper, and the pyrite-to-chalcopyrite ratio is about 10:1; (3) surrounding this zone and still within the phyllic and argillic zone is a 1,000- to 1,500-foot-wide pyrite mineralized zone that ranges in grade from 0.01 to 0.10 percent copper and averages about 0.03 percent copper. The area averages about 0.03 percent copper. The area averages about 10 weight-percent pyrite. The propylitic zone contains a few high-grade silver, gold, and chalcopyrite veins and pervasive pyrite veinlets. Lowell (13) also observed vertical mineral and alteration zones along the original axis of the deposit.

The original unfaulted San Manuel-Kalamazoo deposit was described by Lowell (13) as being a flattened, elliptical cylinder. The deposit was

estimated to be at least 7,700 feet long and from 2,500 to 5,000 feet in diameter at a 0.5 percent copper limit. The width of the ore shell around the low-grade core ranges from 100 to 1,000 feet, and the alteration pattern extends from 3,000 to 5,000 feet beyond the deposit.

The San Manuel ore body was described by Thomas (35) as consisting of two separate limbs converging to the northeast, the center being weakly mineralized. The North limb averages 400 feet wide and dips 55° SE. The South ore body limb is up to 1,000 feet wide and dips southeasterly to vertical and to the northwest. At depth, the limbs flatten and coalesce, resulting in a "U" shape leaning to the northwest. Thomas (35) reported the San Manuel ore body to be 7,700 feet long and up to 2,700 feet deep, the entire mineralized and altered area being 9,300 feet long and 8,000 to 9,000 feet wide. The ore body is almost entirely overlain by the Gila conglomerate and some weakly mineralized monzonite; only a small, oxidized portion of the ore body cropped out. Capping ranges up to 1,900 feet and averages 670 feet in depth.

By 1962, the South limb of the San Manuel ore body had been mined underground on the first or 1,475-foot level over an area about 2,500 feet long and 700 feet wide. At this time the surface showed subsidence of 120 to 140 feet over an area roughly 2,900 feet long and 1,900 feet wide. The time interval between the first undercut in the South limb and the first evidence of surface cracking was approximately 100 days. At the North limb, which is considerably smaller, the time interval before subsidence was about 500 days. Factors contributing to the time interval included areal extent, the height of ore column, rate of draw related to height, competence of overlying rocks, and the shape of the blocks. In 1972, subsidence over both limbs and the areas between totaled as much as 6,400 feet in length and 4,000 feet in width.

The Kalamazoo ore body, as interpreted by Lowell (13), has an overturned-canoe shape (apparently the mirror image of the San Manuel ore body), and the top of the ore body is about 2,500 feet below the surface of the ground.

Production (1, 14-15, 19-21).--Using the block-caving method, Magma Copper Co. brought the San Manuel underground mine into production in 1956 after some 7-3/4 years of construction. The initial designed capacity of mine and mill was 30,000 tpd; the capacity was increased gradually until 1963 to 35,000 tpd. A planned expansion to 40,000 tpd authorized in January 1964 was completed by July 1965. The expansion program begun in July 1968 brought the capacity up to 60,000 tpd; by 1972 the production was 61,440 tpd.

The smelter, with a designed capacity of 360,000 tpy, was completed in January 1956, and by 1971 the capacity was expanded to 670,000 tpy. The electrolytic refinery, with a designed capacity rated at 200,000 tpy of refined copper, was completed in 1972; half of the output was as cathode plate and half as continuous-cast rod. A new continuous-cast-rod plant was also finished in 1972.

The available statistics for the mine production and recovery of copper, molybdenum, gold, and silver, from the San Manuel ores from 1956 to 1971 are shown in table D-1, In 1971, rhenium was recovered from molybdenum concentrates. By 1974, the company will have installed a 2,000-tpd acid plant at the smelter.

TABLE D-1. - San Manuel mine production, 1956-72

Year	Ore mined, tons	Copper sulfide, percent	Payable metal content				Ore milled, tons per day
			Copper, pounds	Molybdenum sulfide, pounds	Gold, ounces	Silver, ounces	
1956	5,539,581	0.754	78,152,140	591,970	9,719	136,074	NA
1957	8,825,130	.755	119,797,769	1,452,080	13,578	200,301	24,357
1958	11,486,300	.716	149,401,672	1,872,450	16,868	253,858	31,997
1959	7,595,867	.719	92,340,444	1,435,613	10,232	158,594	32,533
1960	12,261,220	.710	163,448,339	2,807,671	18,010	290,617	34,053
1961	12,529,243	.727	165,223,023	3,869,166	17,597	295,553	34,249
1962	12,565,545	.748	168,416,024	4,157,051	15,025	302,953	35,165
1963	12,555,000	.795	177,072,298	4,735,771	18,760	310,228	35,139
1964	12,442,752	.828	185,178,000	4,972,000	20,746	282,334	34,756
1965	13,504,024	.773	187,534,000	5,726,000	21,550	273,610	40,312
1966	14,391,355	.772	202,780,000	7,088,000	22,396	311,699	40,091
1967	7,891,854	.758	107,926,000	4,002,000	10,534	166,893	41,463
1968	11,367,640	.701	144,148,000	2,596,000	14,303	245,316	39,840
1969	15,280,816	NA	191,443,365	NA	NA	NA	NA
1970	15,446,474	NA	189,979,096	NA	NA	NA	NA
1971	14,975,910	NA	166,656,905	NA	NA	NA	NA
1972	21,844,943	NA	271,501,061	4,953,567	NA	NA	NA

NA--Not available.

Sources: Arizona Department of Mineral Resources. Copper Industry Statistics (1).
Magma Copper Co. Annual Reports 1956-68 (14).
Newmont Mining Corp. Listing Application to New York Stock Exchange (20).
Newmont Mining Corp. Preliminary Prospectus (18).

Reserves (20).--In 1969, based on an average 0.50 percent sulfide copper as the cutoff grade, the San Manuel sulfide ore reserves were estimated to be 496,800,000 tons of 0.728 percent net sulfide copper before dilution; of this volume 228,500,000 tons of 0.71 percent sulfide copper could be mined from the second or 2,075-foot level. Oxide-ore reserves were estimated to be 130 million tons of 0.70 percent total copper (0.47 percent oxide copper) before dilution, all lying above the second level.

The Kalamazoo ore body was estimated to contain 565 million tons of sulfide ore averaging 0.72 percent net sulfide copper, before dilution.

History.--The area was said to have been prospected before the Civil War (16, 37).[2]

[2]The history of the Kalamazoo property is treated separately at the end of this appendix.

1870 (ca.)	First claims were reportedly staked on Red Hill near the San Manuel deposit (11).
1873, Dec. 27	The Mammoth mine area (about 1 mile north of the present San Manuel mine) was mentioned in the Arizona Citizen newspaper as being worked by "E. M. Pearce, C. O. Brown, and Tully, and Ochoa and Co." (9).
1879-82	Frank Schultz located the Hackney and Aaven claims on the Collins vein in 1879, the Mohawk claim in 1881, and the Mammoth and Mars claims in 1882, in an area about 1 mile north of the San Manuel deposit. The place was first known as Schultz, later Tiger, and was also called the Mammoth mining camp and the St. Anthony area. The mining camp lies 3 miles southwest of the town of Mammoth (5, 29, 31).
1881-1947	Production at the Mammoth mining camp from 1881 to 1947 totaled 1,887,375 tons of ore containing 386,701 ounces of gold, 983,918 ounces of silver, 3,456,121 pounds of copper, 74,730,289 pounds of lead, 48,272,654 pounds of zinc, 6,314,812 pounds of MoO_3, and 2,540,842 pounds of V_2O_3. This production was from the Mammoth, Collins, and Mohawk-New Year mines. These mines were consolidated in 1934 and later operated as the St. Anthony Mining and Development Co. Ltd. (5).
1906	Some claims now on San Manuel property were staked during this year and then held more or less continuously through the years (31).
1910 (ca. June)	Magma Copper Co., organized under the laws of Maine with a capitalization of 1 million shares at $1 par, was founded by William Boyce Thompson. Properties held under bond and lease at that time included those of Lake Superior & Arizona Mining & Smelting Co. and Silver Queen Mining Co., about 8 miles west of Miami and 12 miles north of Ray, Ariz. (34).
1915-17	Between 1915 and 1917 two holes were churn-drilled just southeast of Red Hill where copper mineralization, principally chrysocolla, crops out; low-grade (0.8 percent) oxidized copper may have been penetrated (6). The holes penetrated the pyritic mineralized zone that forms the footwall of the present ore body (31). Walter H. Aldridge did the work for the William Boyce Thompson interests that were associated with Magma (6).
1921, May 2	Newmont Corp. was incorporated in Delaware to manage the William Boyce Thompson interests.
1925, Feb.	The name Newmont Corp. was changed to Newmont Mining Corp., and 130,000 of the outstanding 430,000 common shares were offered to the public at $40 per share (19).

1925, Jul. 1	Anselmo Laguna located the original San Manuel Nos. 1-5 claims on July 1, 1925 (31).
1926-40	James M. Douglas bought one-third interest in the San Manuel claims June 18, 1926, and another one-third interest August 19, 1939, James Douglas and R. Burns Giffin bought the remaining one-third interest October 25, 1939. Douglas and Giffin deeded Victor Erickson a one-fourth interest in the claims on March 29, 1940. Before Laguna died, he reportedly had taken R. Burns Giffin as a partner (11, 31).
1941	Douglas, Giffin, and Erickson offered their San Manuel property to Magma Copper Co. for $50,000; however, the company's engineer reported there was no apparent value (11).
1942	Giffin took an option on the property but let it expire in 1942 (11).
1942, Apr.	The partners asked Henry W. Nichols, an assayer for Magma, for technical assistance. Nichols examined the property, wrote a report, located some new claims for the owners, and also tried to interest Magma Copper Co. (11).
1942, Aug.	The partners gave Nichols one-fourth interest in the partnership (31).
1942, Oct. 11	Together with his report on the San Manuel claims, Nichols submitted an application for a $20,000 loan at the Reconstruction Finance Corp. (RFC), Phoenix, Ariz., office. The loan request was for drilling holes to prove enough ore to warrant building a mill (11, 31).
1943, Jan. 22	Wm. B. Maitland examined Nichols' report for the RFC (31).
1943, Mar. 10	Apparently the RFC rejected Nichols' loan application on this date. Because of the urgency of obtaining copper for the World War II efforts, other Government agencies became interested in the area. After much correspondence with the owners, RFC, and the War Production Board (WPB), the U.S. Geological Survey undertook an initial study of the area (31).
1943, Mar. 6-19	N. P. Peterson and B. S. Butler of the U.S. Geological Survey mapped, studied, examined, and sampled the outcrops, and recommended further exploration (31).
1943, May 22-26	T. L. Chapman and W. D. Hughes of the Federal Bureau of Mines examined the property, reviewed the U.S. Geological Survey and Nichols' reports, and then recommended a preliminary drilling program (31). Old workings, which had been previously excavated principally in order to satisfy assessment requirements, were

examined during the Bureau of Mines investigation. Such workings included a 100-foot shaft, nine shallow shafts, a tunnel, and some trenches and pits on the San Manuel ground. Three shafts were in copper ore, including a 60-foot vertical shaft and a 25-foot incline shaft under the conglomerate hanging wall. A 160-foot tunnel was in a copper-bearing diabase dike that marked one boundary of the ore body (4).

1943, May to July	The partners offered to sell the San Manuel property to various people with no takers (11).
1943, Aug.	The Bureau of Mines concluded an agreement to drill the San Manuel deposit (11).
1943, Nov. 23	The Bureau of Mines started churn drilling; authorization was for five holes, each about 300 feet deep. The drill grid coordinate system nearly paralleled the western tabular-shaped part of the ore body. Preliminary holes were based on geology and topography; later holes were set at 400-foot intervals in an east-west direction and at 200-foot intervals in a north-south direction (31).
1944, Jan. 15	Project funds were exhausted. Work on four holes had been completed to 300 feet and on the fifth to 200 feet. Rock penetrated included Gila(?) conglomerate and altered monzonite porphyry. Continuous low-grade copper oxide ore showed in all footage below the conglomerate (31).
1944, Feb. 9-Mar. 31	The Geological Survey prepared a plane table map of the area (31).
1944, Mar. 28	The Bureau of Mines allocated funds for drilling to reach sulfide ore (31).
1944, May 27	Bureau of Mines hole 6 reached sulfide ore for the first time at 685 to 690 feet. Assays taken in a 20-foot zone of oxidation averaged 0.797 percent copper, assays in the 340-foot secondary sulfide zone averaged 1.02 percent copper, assays in the 150-foot zone of variable weak enrichment averaged 0.728 percent copper, and assays in the 235-foot zone of partly oxidized pyritic ore averaged 0.202 percent copper. The hole bottomed at 1,410 feet (31).
1944, June	The partners continued to approach various mining companies in an attempted to sell or drill the claims. John Gustafson, geologist for the Magma mine of Magma Copper Co. at Superior, Ariz., made a brief reconnaissance of the claims at Red Hill and expressed interest in the property (11).
1944, Aug.	The Bureau of Mines received additional funds to resume drilling (31).

1944, Aug. 25 — After a more thorough examination, Gustafson submitted to Magma a detailed report on the San Manuel property, which summarized the situation and outlined problems and steps to be taken to determine the ore body size. The New York office of Magma approved a verbal agreement that Gustafson had arranged with the partners (11).

1944, Aug. 31 — Magma Copper Co. signed an option agreement with the partners for a group of 21 claims known as San Manuel. Options were also obtained on two contiguous groups, seven claims in one and six claims in the other. The option on the 21 claims stipulated that after 1 year from the date of the option Magma would form a corporation to acquire, develop, and operate the property. Depending on size and grade of the ore body, the vendors were to receive shares in the new corporation, but no more than 10 percent of the total shares. Magma Copper Co. was to receive an option to purchase unissued shares in the corporation. Magma also located 35 claims on surrounding property (14).

1944, Sept. — Magma purchased the claims adjoining its property held by Apex Lead Vanadium Mining Corp. and the Quarelli family (37). In the following 19 plus years, San Manuel Copper Corp. (see August 1945) and its subsidiaries obtained additional patented and unpatented claims for mining, ranch and desert lands for concentrator, tailings, smelter, refinery, and town sites, and other lands. These acquisitions included 135 lode mining claims covering about 2,542 acres leased from the State of Arizona. In 1947, San Manuel applied for patents on 84 unpatented claims; patents were granted on 82 by 1950 (14).

1944, Dec. — Magma commenced exploration by churn drilling. From December 1944 to February 17, 1948, 88 holes totaling 172,692 feet were drilled; the deepest was 2,755 feet. Only one hole was core-drilled (31).

1945, early — Under the name of the Houghton group, Thomas Lyon of International Smelting and Refining Co., and Associates obtained an option and working agreement between San Manuel and the Mammoth-St. Anthony mines. The Anaconda Co. commenced churn-drilling on these claims. Eighteen holes were drilled for a total of 27,908 feet; the deepest was 2,000 feet (4, 6, 31).

1945, Feb. 2 — The Bureau of Mines drilling program ended with the exhaustion of alloted funds. Seventeen holes totaling 15,839 feet had been drilled by February 1945; the maximum hole depth was 1,990 feet. The delineated area was 3,100 feet long by 400 to 800 feet wide by 500 to 700 feet thick; the ore averaged about 0.8 percent copper (4). Chapman (4) reported that half the ore was oxidized, with the bulk of the copper in chrysocolla. Total cost of churn drilling was $96,253.67, averaging $6.077 per foot (6).

1945, Aug.	In accordance with the agreement between Magma and the vendors (partners), San Manuel Copper Corp. was incorporated in August 1945 under the laws of Delaware, with an authorized capital of 1,500,000 shares with a par value of $1 each. San Manuel became a subsidiary of Magma Copper Co. to carry on exploration. The vendors received 75,000 shares of San Manuel Copper Corp. in exchange for their mining claims and, depending on the tonngage and grade of ore developed in certain defined areas, were possibly entitled to an additional 75,000 shares. By December 31, 1946, 515,000 shares of San Manuel Copper Corp. were issued and outstanding. Magma Copper Co. owned 458,941 shares, and the vendors owned 56,059 shares.
	San Manuel Copper Corp. executed an option agreement whereby Magma Copper Co. received the exclusive right and option to purchase all unissued shares, at up to $10 per share, including all or such portion of the shares reserved for the vendors to which they might not be entitled (14).
1945, Sept. 17	Magma exercised its option to obtain the San Manuel property (14).
1948-1953	This period was one of underground exploration and development (31). Time intervals for sinking five shafts are shown in table D-2.
1948, Mar. 17	Exploration by churn drilling essentially was completed; 109 holes, totaling 205,536 feet, had been drilled at a cost of over $2.5 million (2). Collared March 17, 1948, the No. 1 shaft, located north of the ore zone, was to be used for lowering supplies for development work and as a downcast ventilation shaft; completed in January 1952, the shaft was 1,643 feet deep (31).
1948, Oct.	No. 2 shaft, collared over the southeast limb of the ore body, was to permit early exploration, development, testing the characteristics of the ore, and studying the flow of water and drainage. Completed in 1951 to a depth of 2,068 feet, the shaft was abandoned by late 1958 (5-6, 14).
1950	The Government granted patents to 82 lode mining claims consisting of 1,458+ acres (14).
1950, Dec.	Drifting from the No. 2 shaft was begun on the 1285 level to explore the southeast limb of the ore body. Diamond drilling and sampling on that level outlined the ore body and explored an area not covered in churn drilling (5).
1952, Jan.	Sinking of the No. 1 shaft was completed at a depth of 1,643 feet (14).

TABLE D-2. - General shaft sinking data at the San Manuel mine

Shaft and location	Initial sinking			Rate of sinking, average per month, feet	Purpose	Type of construction, size, and shape	Number of compartments	Depth (1972), feet	Planned expansion		Planned depth, feet
	Depth,[1] feet	Date started	Date completed						Depth, feet	Date of starting (s) or completion (c)	
No. 1, north of ore zone, elevation 3,340 ft	[2]1,643	Mar. 1948.	Jan. 1952	88.1	Exploration and development, downcast ventilation, concrete supply, and development waste rock. 3d lift	Structural steel, reinforced concrete. 25.5 by 6 ft rectangular	4	2,833	NAp	NAp	2,833
No. 2, near center of south ore body.	2,064	Oct. 1948.	Ca. Apr. 1951.	110.5	Exploration and development.	Timber, 18.5 by 5.5 ft.	3	Abandoned	NAp	NAp	NAp
Nos. 3A and 3B. Twin shafts, 195 ft apart, southeast of ore zone.	A-1,708 B-1,707	Sept. 1953.	Ca. Mar. 1955.	A-115.2 B-111.3	Ore hoisting and upcast ventilation for 1st lift.	Structural steel, reinforced concrete. 29 by 7 ft rectangular	4	A-2,305 B-2,305	A-2,950 B-2,950	A-1975(s) B-1976, mid(s).	A-2,866 B-2,866
No. 3C, north of 3A, 195 ft.	2,859	Nov. 1968.	Apr. 1971	NA	Ore hoisting and exhaust ventilation.	Structural steel, reinforced concrete, 22 ft circular.	4	2,859	Deepening	1977, mid (s).	2,859
No. 3D, south of 3B, 195 ft.	3,713	May 1971.	Scheduled 1973.	NA	.....do........	.....do.........	4	2,894	3,740	1973, end (c)	3,713
No. 4, northwest of ore zone, 600 ft from No. 1 shaft.	1,582	July 1953.	Dec. 1954	127.5	Supply, service and downcast ventilation.	Structural steel, reinforced concrete, 25.5 by 14 ft rectangular, rounded ends.	4	2,730	NA	NA	2,730
No. 5 approximately 400 ft north of 3C.	4,383	Nov. 1968.	Scheduled Oct. 1973	NA	.....do........	Structural steel, reinforced concrete, 25 ft circular.	4	3,910(?)	4,280	1973, Oct.(c)	4,383

NA--Not available. NAp--Not applicable.

[1]With the exception of the No. 2 shaft, these shafts were deepened sporadically as mine exploration and development proceeded on various levels. The production levels were 1,415 and 1,475, 1,715 and 1,775, and 2,015 and 2,075. Future production will be from the 2,615 and 2,675 levels. The Kalamazoo ore body will be mined from the 3,380 and 3,440 levels. The 1,285 level was an exploration level for the San Manuel ore body, and the 2,675 level was the exploration level for the Kalamazoo ore body. The 3,380 grizzly level and the 3,340 haulage levels are production levels for the Kalamazoo ore body.

[2]2,833 ft in 1971.

Sources: Creasey, S. Geology of the San Manuel Area, Pinal County, Arizona (5).
Dale, V. B. Mining, Milling and Smelting Methods, San Manuel Copper Corp., Pinal County, Arizona (6).
Magma Copper Co. The San Manuel Mine General Information Booklet (16).
Skillings' Mining Review. Magma Copper Co. Construction and Expansion in Arizona (33).
Magma Copper Co. Personal communication (17).

1952, May	Drifting was begun on the 1475 haulage level from No. 2 shaft (4). this level was for development and exploration (14).
1952, July	On July 10, the Reconstruction Finance Corp. (RFC) granted San Manuel Copper Corp. a $94 million loan to be used for mine development, plant construction, and equipment. The note would mature in 20 years and had a 5-percent annual interest rate. Payments on account of principal of the note were required in the amounts of $1,550,000 quarter-annually beginning January 1, 1959, or 2 years after completion of the project, whichever was earlier, together with annual payments of certain earnings of the corporation. The note was secured by a first mortgage on the San Manuel Copper Corp. property. Magma Copper Co. guaranteed the RFC load and agreed to advance certain of its earnings to the San Manuel Copper Corp. during the period of the load. No cash dividends were to be paid by Magma Copper Co. during the life of the RFC loan. Before San Manuel Copper Corp. received the Government loan, Magma Copper Co. had advanced San Manuel Copper Corp. about $10 million (6, 14).
	Based on authorization of the RFC loan, the exploration period could be assumed ended.
1952, Aug.	An August 29 agreement with the Defense Materials Procurement Agency and the San Manuel Copper Corp. stipulated that the Government could purchase or be required to purchase all or substantially all the corporation's first 5-1/2 years of estimated production of refined copper and molybdenum concentrates. The agreement was for the purchase of 347,500 tons of copper at 24 cents per pound from the first 365,000 tons produced, and 15,330 tons of molybdenum concentrate at 60 cents per pound from the first 16,060 tons produced. Prices were subject to adjustment with increased wages and cost of materials; however, the Corporation could sell on the open market when prices were higher than the contract prices (6, 14).
	Exploratory drifting on the 1285 level from the No. 2 shaft was completed (14).
1952, Nov.	Drifting was begun on the 1415 grizzly level from the No. 2 shaft (5).
1953, Jan.-1956, Jan. 23	Major mine development was begun about January 1953, and initial production began in early 1956 when the first stope undercut was completed (2). By the end of 1955 the development necessary for production, exclusive of stope development, totaled 8,708 feet of shaft, 97,463 feet of drift, and 116,998 feet of diamond-drill hole (5).
1953	Final agreement was made with Del E. Webb Construction Co. and M. O. W. Holmes, Inc., to finance and build a town for serving the needs of the people of the San Manuel operation (14).

San Manuel Arizona Railroad Co. was incorporated in Arizona. The company commenced construction of a railroad from the concentrator to the Southern Pacific Railroad near Hayden, a distance of 29.5 miles; the railroad was completed January 1955 (14).

A contract was made with Arizona Public Service to supply power for the entire operation during construction and production. Part of a substation was installed and power was made available (14).

1953, early — In a joint venture, the Utah Construction Co. and The Stearns-Roger Manufacturing Co. were awarded a contract covering the design and construction of the entire surface plant, including the concentrator, smelter, railroads, and auxiliary facilities (14).

1953, Feb. 5 — Magma Copper Co. issued 10,000 shares of its capital stock in exchange for substantially all of the adjoining St. Anthony Mining and Development Co., Ltd., property. The ground was to be used principally for living quarters for the San Manuel project (14).

1953, July — The No. 4 shaft was collared 600 feet from the No. 1 shaft on the northwest side of the ore zone. The shaft was to be used for downcast ventilation and to provide service, supplies, and equipment to the 1415 and 1475 levels. Preliminary work on the shaft started July 19, 1953, and continued to December 26, 1953, when contract work was begun. This contract work was completed December 28, 1954. The initial sinking of the shaft went to 1,582 feet (6).

Excavation of the plant site commenced (14).

1953, Sept. — No. 3A and No. 3B shafts were collared 165 feet apart southwest of the ore zone. The shafts, to be used for production and upcast ventilation, were completed to the 1737 level by 1955 (5, 30).

1954, July — A commercial center, park, and 1,000 housing units were completed (14).

1955, early — Magma Copper Co. acquired the San Manuel townsite, buildings, and physical assets by an exchange of stock with the original developers. Additional facilities, including a hospital and three schools, were constructed (14).

1955, end Sept. — The 30,000-tpd concentrator and crushing plant were completed, and treatment of stockpiled and mine development ore commenced (14, 35).

1956, Jan. 8	The smelter was finished, and the first copper anode was poured. Smelter construction, from design to completion, took about 3 years; the smelter was designed to produce 70,000 tons per year of copper (11).
1956, Jan. 23	The first block was undercut, and production started, using the block-caving method of mining (14).
1956, Apr.	The molybdenum sulfide section of the concentrator was put into operation (14).
1956, end	By yearend, six caving blocks on the 1415 level had been placed into production, and surface subsidence had occurred over more than 1.4 million square feet (6). Total capital expenditures at San Manuel by December 31, 1956, including the railroad but excluding the townsite, were $102,589,445. Distribution was $1,150,847 for property, $27,701,948 for deferred development, and $73,736,650 for the plant. Of the total, $88,587,000 was expended on the "production project," which commenced January 1, 1952, and was substantially completed by December 31, 1956 (14).
1957, Oct. 16	The mine attained its scheduled output of 33,000 tons of ore per day. Development of the 2015 and 2075 levels was in progress (6).
1957, end	Twelve blocks above the 1475 level had been placed in production by yearend (6).
1958, early	The mine achieved full production (36).
1958, Feb.	The first block was drawn to completion (6).
1960, July	The "Cyanide plant for the recovery of gold from the molybdenum sulphide concentrate was completed in July 1960..." (14).
1962	Production was begun on the 2075 level (second level) (32). Early in the year Newmont Mining Corp. increased its ownership in Magma Copper Co. from 21.5 percent to 80.6 percent (19). By February 1, 1962, San Manuel Copper Corp. had reduced the U.S. Government loan of about $77 million to $65.5 million (18).
1962, Apr. 30	San Manuel Copper Corp. and San Manuel Townsite Co., wholly owned subsidiaries of Magma Copper Co., transferred all their properties and assets to Magma Copper Co. and were dissolved as separate corporations. Magma formed the San Manuel Division to operate the property and the San Manuel Townsite Division to take

care of the San Manuel townsite. The railroad subsidiary (San Manuel Arizona Railroad Co.) remained as a separate corporation (14).

1963 Feb. The remaining amount of the Government loan was fully repaid on February 8 with a $54 million loan from Prudential Insurance Co. of America. The maturity date on the new loan was extended from 1973 to 1982; payments at a 5-1/2-percent interest rate were to be made semiannually beginning in 1965. This refinancing allowed Magma to resume payment of cash dividends; development of the company's properties was now less restricted than under the Government loan (14).

Magma Copper Co. entered into a lease and option agreement with The Anaconda Co. for the Anaconda property adjoining the San Manuel mine and containing a small part of the San Manuel ore body. The lease, to expire December 1987, required yearly rent or royalty payments beginning January 1964. The option to purchase was to expire July 1983 (14).

1964, Jan. A decision was made to install a primary crushing plant and additional grinding and flotation circuits in the concentrator for treating an additional 4,000 tpd. Expansion, scheduled for completion by mid-1965, was estimated to cost $11,800,000 (14).

1964, Jan. 9 The sodium hypochlorite-ferrocyanide process used from 1956 to 1964 was modified to increase plant capacity and molybdenum recovery, and to reduce corrosion rate and the high maintenance costs caused by the hypochlorite process (3).

1965, Jan. The 1475, or first, level was mined to completion in January 1965 (14, 26).

1965, July Expansion from 35,000 to 40,000 tpd was completed. Work, under the direction of Stearns-Roger Corp., included installation of crushing facilities at the collar of the two ore shafts, expansion of other plant facilities, and installation of a new reverberatory furnace at the smelter (8, 14).

1968 "The Kalamazoo copper property was purchased by Magma from Quintana Minerals, Ltd. in March, 1968, for $27,000,000, made up of $15,000,000 in cash and 212,390 shares of Magma common stock having a then market value of $12,000,000. Under Magma's agreement with Quintana and Newmont Mining Corporation, Quintana received from Magma $15,000,000 in cash and $42,478 shares of Magma stock and from Newmont $4,800,000 in cash and 78,208 shares of Newmont common stock and Newmont received from Magma 169,912 shares of Magma stock" (14, 1968, p. 6). The Kalamazoo property is west of the San Manuel property, and the ore body is estimated to contain 565 million tons of sulfide ore averaging 0.72 percent net sulfide copper (14). The top of the ore body is about

2,500 feet below the surface. Plans were to open the deposit for exploration on the 2950 level sometime after 1972 (26). (See history of Kalamazoo property at the end of this appendix.) On July 22, Magma authorized an expansion program at San Manuel and Superior Divisions. At San Manuel, production capacity was to be increased from 40,000 to 60,000 tpd; capacity at Superior was to be increased to 3,000 tpd. The cost for both projects was expected to exceed $100 million. The Stearns-Roger Corp. was awarded the contract for engineering and construction of surface facilities at both mines, with construction expected to start in the second quarter of 1969 (14).

In the third quarter contracts were awarded to Cementation Co. of America, Inc., for sinking shafts at San Manuel and to Stearns-Roger Corp. for the design and construction of additional surface facilities. Completion of the projects was expected to take 3 to 4 years (15).

Expansion at San Manuel included--

No. 1 development shaft was deepened 600 feet and completed in early 1969. Since then excavation for stations below 2075 feet and development of 2375 (intermediate) level and the 2675 (third) level has been underway. Production was expected from the 2375 level in mid-1974, and from the 2675 level in 1978--following 7 years of development (32).

No. 4 service shaft, used for men, supplies, and downcast ventilation, was to be deepened 600 feet (32).

No. 3C production shaft for production and exhaust ventilation was started November 1968 and completed April 1971. The 22-foot-diameter shaft was concrete lined; skip-loading stations were put in at the 2075, 2375, and 2675 levels. Ore production was scheduled to begin in the first quarter of 1971 from the 2075-foot level.

No. 3D production shaft, started May 1971, was a 22-foot-diameter, circular, concrete-lined shaft; completion of a 3,700-foot-deep shaft was expected by 1973 (26, 32).

No. 5 shaft, to be used for men, supplies, downcast ventilation, and hoisting development rock, was started November 1968. This 25-foot-diameter, circular, concrete-lined shaft has five stations. The final depth was planned to be 4,350 feet, the bottom of the Kalamazoo ore body (26, 32).

1969, May 6 — To facilitate financing the 50-percent expansion that became possible with the purchase of the Kalamazoo ore body, Newmont acquired all the remaining Magma shares and reincorporated Magma as a wholly owned subsidiary (19).

1970 — Power was to be increased by the addition of a 12,600-kw turbo-generator and a new 115-kv-a transmission line built by Arizona Public Service from Oracle, Ariz. The present power supply at

San Manuel was obtained from a 10,000-kw steam-driven turbo-generator supplied by waste-heat boilers and from Arizona Public Service (32).

1970, Mar. Work was begun on a refinery designed for 200,000 tpy, or about 650 tpd, of copper with the capability for expansion up to 300,000 tpy. The first cathodes were produced September 16, 1971 (24).

1971 In 12 months of operation the average daily mine production was 44,500 tons (16). In November, mine and mill production reached 58,000 tpd, just slightly less than the designed capacity of 60,000 tpd (25).

Rich rhenium-bearing molybdenite was recovered from porphyry copper ores at the San Manuel mine. In 1971, this material was sold to Shattuck Chemical Co., Denver, Colo., a division of Engelhard Minerals & Chemicals Corp., and rhenium salts were recovered. M&R Refractory Metals, Inc., produced rhenium salts primarily from Magma concentrates for Engelhard on a "toll" or contract conversion basis at their plant in Winslow, N.J., with recoveries reportedly in excess of 60 percent. Approximately 1,200 tpy of molybdenite concentrate is processed in this facility (35).

Newmont Mining Corp. announced plans for engineering the first flash-copper smelter to be planned in the United States; Western Knapp Engineering Div. of Arthur G. McKee & Co. received the contract. Outokumpu Oy, Helsinki, Finland, which developed and used the method in 1949, was to assist McKee. Plans were to replace one or more of the existing reverberatory furnaces with one or more flash smelting furnaces. A sulfuric acid plant was to be installed to recover SO_2 from smelter gases. By the end of 1973 the smelter with the new emission-control system was to process up to 710,000 tpy of copper concentrates. Total smelting capacity was planned to expand to 1 million tpy. Pollution-control facilities were estimated to cost $50 million (23).

Newmont joined other copper companies to form the Smelter Control Research Association, a nonprofit organization for research and pilot plant work for improving removal of sulfur dioxide from smelter stack emission. To test the use of wet limestone and other alkaline reagents to remove SO_2 from reverberatory gas, the association operates a pilot plant at the Kennecott smelter, McGill, Nev. (19).

1971, Dec. The electrolytic refinery was completed within the estimated $31 million cost. The refinery, with an annual capacity of 200,000 tons of refined copper, was to produce half of the output as cathode plate and half as continuous-cast rod (19).

1972 The new 200,000-tpy electrolytic copper refinery and the 100,000-tpy continuous-cast copper rodmill at San Manuel were dedicated January 29, 1972. Expansion programs of production and processing facilities and underground development at San Manuel and Superior were estimated to cost over $250 million. Also included were the enlargement of the concentrator, additional crushing facilities, erection of the smelter stack (550 feet), and construction of new homes for employees (26). Smelter capacity was planned to be raised from 100,000 tpy to 200,000 tpy (7).

1972, early The Industrial Development Authority of Pinal County (IDA) and Magma Copper Co. agreed to study a $53 million bond program for the San Manuel facilities to meet Federal and State standards of emission control. One estimate of the cost of the facilities amounted to $100 million. IDA is a nonprofit independent organization established in September 1970, under a 1968 law, to sell tax-exempt bonds to finance construction of industrial facilities (21).

Plans to install flash furnaces and a three-module acid plant to handle gases from furnaces and smelter converters were canceled when the cost of installation was estimated to be from $81 to $88 million. The company then planned to build an acid plant to handle only converter gases. On February 25 State Air Pollution Control Board granted Magma a 1-year renewal of its conditional permit to operate its San Manuel smelter (19, 27). The conditional operating permit was granted on the basis of a two-stage compliance plan: (1) Beginning in 1972, construction of a sulfuric acid plant to treat converter gases, and (2) development of a limestone-scrubbing process to treat reverberatory furnace gases (19).

1972, Feb. The mine and concentrator were operated up to 65,000 tpd (19).

1972, end Production for the year averaged about 61,440 tpd; a maximum 71,000 tpd was achieved early in the year (17). Progress and planning of shaft sinking by 1972 included (16, 33):

No. 4 shaft had been deepened to 2,730 feet by yearend.

Nos. 3A and 3B shafts were at 2,305 feet (for the second lift) by yearend. Plans were to sink both shafts to 2,866 feet and later to 2,950 feet--the 3A shaft beginning in 1975, and the 3B shaft beginning by mid-1976.

No. 3C shaft, completed to 2,859 feet by April 1971 (hoisting started August 1971), was scheduled for expansion beginning in 1977.

No. 3D shaft was sunk to 2,894 feet by yearend 1972 and was scheduled for completion to 3,713 feet by yearend 1973.

No. 5 shaft was sunk to 3,910 feet and was scheduled for completion to 4,280 feet by October 1973.

1973, Mar. 5 — The State Air Pollution Control Hearing Board granted Magma a 1-year renewal permit to operate the San Manuel smelter in variance with the State air quality regulations. The company's $47 million program to comply with these regulations included: (1) installation and modifications (begun February 28, 1972) to the converter gas collection system--replacement of converter hoods was begun June 8, 1972; (2) construction of an acid plant (engineering started June 6, 1972) designed to accommodate converter gas at the ultimate planned capacity of 1 million tons of concentrate per year; (3) installation of additional electrostatic precipitator capacity, which was required because the alkaline scrubbing of reverberatory furnace gas was eliminated; (4) installation of a closed-loop system; (5) establishing six monitoring stations; (6) employment of a staff meteorologist; and (7) destruction of excess acid (28). Estimated production of acid by 1974 was 1,638 tpd, with a marketing outlet planned for 85 percent of the total. Final production capacity of acid was expected to be 2,072 tpd. To dispose of excess acid, it was proposed to neutralize the acid in a slurry of powdered limestone and incorporate it with the tailings (28).

History of Kalamazoo Property

1946 — Frank F. Salas, R. A. Buzan, H. G. Buzan, and W. C. Buzan of Mammoth, Ariz., staked mining claims covering the area immediately west of the San Manuel ore body (12).

1946 — Martha Purcell optioned the claims (12).

1947-58 — Seven churn-drilled holes ranging in depth from 1,400 to 2,850 feet put down by Mrs. Purcell did not intersect ore (12).

1965 — Quintana Minerals, Ltd., of Houston, Tex., began exploration work. The geologic and assay logs and drill-cutting samples from the Purcell drill holes were reviewed. Four of the seven holes showed an alteration pattern similar to that of the San Manuel ore body. One hole appeared to bottom in an area typical of the San Manuel marginal mineralization zone. A geochemical soil survey in the preore outcrop area of the Purcell claims showed a moderately well defined copper and molybdenum anomaly, which was later found to overlie the Kalamazoo ore body. Based on data compiled from U.S. Geological Survey Professional Paper 256, a structure contour map of the San Manuel fault was made. A new interpretation of the geology evolved (12).

1965-67 J. David Lowell, consulting geologist, Tucson, Ariz., determined the possible location of an ore body and directed the Quintana exploration project. The Kalamazoo ore body was located by the first drill hole that was spotted according to the normal faulting interpretation and other evidence. The first Quintana drill hole passed through propylitic and quartz-sericite alteration zones, going from pyritic and marginal mineralized zones into ore-grade mineralization at about 2,500 feet. The ore body axis was estimated to be about N 57° E. A 600-foot rectangular grid was centered on the first drill hole and laid out using the N 57° E and N 33° W alinements. Twenty-five holes were drilled to an average depth of 4,000 feet (12, 22). Holes were drilled to about 3,000 feet by a rotary drill rig; when cuttings assayed 0.2 percent copper, coring was started. The last 1,000 feet, which contains the marginal and ore zones, was drilled with an NX wireline core drill (12).

1968, Mar. Magma Copper Co. purchased the Kalamazoo property from Quintana Minerals, Ltd. (14).

REFERENCES

1. Arizona Department of Mineral Resources. Copper Industry; Statistics for (year) Compared with Other Years, Arizona, United States and World (title varies). Phoenix, Ariz., annual publications 1969 through 1972.

2. Buchanan, J. F., and F. H. Buchella. History and Development of the San Manuel Mine. Trans. AIME, v. 217, 1960, pp. 394-404.

3. Burke, H. K., and J. F. Shirley. San Manuel's New Process for the Recovery of Molybdenite. Pres. to Soc. Min. Eng., AIME, Chicago, Ill., Feb. 14-18, 1965, AIME Preprint No. 65 B 10, 24 pp.

4. Chapman, T. L. San Manuel Copper Deposit, Pinal County, Ariz. BuMines RI 4108, 1947, 93 pp.

5. Creasey, S. C. Geology of the San Manuel Area, Pinal County, Arizona, with a section on Ore Deposits by J. D. Pelletier and S. C. Creasey. U.S. Geol. Survey Prof. Paper 471, 1965, 64 pp.

6. Dale, V. B. Mining, Milling and Smelting Methods, San Manuel Copper Corp., Pinal County, Ariz. BuMines IC 8104, 1962, 145 pp.

7. Dayton, S. H. (ed.). Magma Closes Mine to Market Gap. Eng. and Min. J., v. 173, No. 4, April 1972, p. 73.

8. Engineering and Mining Journal. San Manuel Expands to 40,000 TPD. V. 167, No. 3, March 1966, pp. 104-105.

9. Granger, B. H. Arizona Place Names. University of Arizona Press, Tucson, Ariz., 1960, p. 298.

10. Johnson, G. H., and J. H. Soulé. Measurements of Surface Subsidence, San Manuel Mine, Pinal County, Ariz. BuMines RI 6204, 1963, 36 pp.

11. Knoerr, A. W. (ed.). San Manuel--America's Newest Large Copper Producer. Eng. and Min. J., v. 157, No. 4, April 1956, pp. 75-100.

12. Lowell, J. D. Geology of Kalamazoo Orebody. Econ. Geol., v. 63, No. 6, 1968, pp. 645-654.

13. Lowell, J. D., and J. M. Guilbert. Lateral and Vertical Alteration-Mineralization Zoning in Porphyry Ore Deposits. Econ. Geol., v. 65, No. 4, June-July 1970, pp. 373-408.

14. Magma Copper Co. Annual Reports, 1944-68.

15. _____. Interim Report, October 1968.

16. Magma Copper Co., San Manuel Division. The San Manuel Mine General Information Booklets. Ca. 1971 and 1972, various pages.

17. Magma Copper Co., San Manuel Division. Personal communication. Available upon request from L. B. Burgin, Bureau of Mines, Denver, Colo.

18. Newmont Mining Corp. Preliminary Prospectus. Mar. 14, 1962, 57 pp.

19. _____. Annual Reports, 1968-72.

20. _____. Listing Application to New York Stock Exchange. May 5, 1969, 59 pp.

21. _____. Semi-annual Report. June 30, 1971.

22. Pay Dirt. Kalamazoo Orebody Sells for $27 Million. No. 346, Apr. 29, 1969, p. 6.

23. _____. Magma Picks Contractor for Flash Smelter. No. 383, May 31, 1971, p. 15.

24. _____. Magma Produces First Electrolytic Copper At San Manuel. No. 387, Sept. 27, 1971, pp. 1, 5.

25. _____. Faulty Equipment Delays San Manuel Production Goals. No. 389, Nov. 29, 1971, p. 18.

26. _____. Magma To Dedicate New San Manuel Refinery. No. 391, Jan. 24, 1972, pp. 22, 24-28, 32, 58.

27. _____. Magma Alters Smelter Plan, Gets One-Year Permit. No. 393, Mar. 27, 1972, p. 19.

28. _____. Magma Gets San Manuel Smelter Permit Renewal. No. 405, Mar. 26, 1973, p. 7.

29. Peterson, N. P. Geology and Ore Deposits of the Mammoth Mining Camp Area, Pinal County, Ariz. Ariz. BuMines Bull. 144, 1938, 63 pp.

30. Pillar, C. L. Progress on Three Big Shafts Reveals Up-to-Date Sinking Practice. Min. Eng., v. 6, No. 7, July 1954, pp. 688-695.

31. Schwartz, G. M. Geology of the San Manuel Copper Deposit, Arizona. U.S. Geol. Survey, Prof. Paper 256, 1953, 65 pp.

32. Skillings, D. N., Jr. San Manuel Copper. Skillings' Min. Rev., v. 59, No. 9, Feb. 28, 1970, pp. 1-3, 6-9.

33. Skillings' Mining Review. Magma Copper Co. Construction and Expansion in Arizona. V. 61, No. 53, Dec. 30, 1972, p. 21.

34. Stevens, H. J. The Copper Handbook. Horace J. Stevens, Houghton, Mich., v. 10, 1910-11, 1902 pp.

35. Stevens, R. F., Jr. Rhenium. BuMines Minerals Yearbook, 1971, v. 1, 1973, pp. 1022-1029.

36. Thomas, L. A. The San Manuel Orebody. Ch. in Geology of the Porphyry Copper Deposits, Southwestern North America, ed. by S. R. Titley and C. L. Hicks. University of Arizona Press, Tucson, Ariz., 1966, pp. 133-142.

37. Tuck, F. J. Stories of Arizona Copper Mines. Ariz. Dept. Mineral Resources, 1957, pp. 46-50.

APPENDIX E.--HISTORICAL DEVELOPMENT OF THE TWIN BUTTES PROPERTY

Ownership.--In 1972, The Anaconda Co. operated the Twin Buttes property under a lease from Banner Mining Co. In June 1973, American Metal Climax, Inc. (AMAX), acquired Banner; AMAX and Anaconda, as equal partners, then formed Anamax Mining Co. to operate the property.

Location (fig. E-1).--The Twin Buttes mine is in secs 5 and 6, T 18 S, R 13 E, in the Pima (Twin Buttes camp) mining district, Pima County, Ariz. The property, about 25 miles south of Tucson, lies in the foothills of the Sierrita Mountains, west of the Santa Cruz River.

Climate.--Summers are hot; winters are mild; annual rainfall is 8 to 10 inches.

Topography.--Sloping gently to the east, the relatively flat terrain is broken by small dry washes running easterly. Altitudes range from 3,200 to 3,800 feet. The mine is at 3,350 feet. Twin Buttes, just north of the mine, has a maximum altitude of 3,740 feet.

Geology (8, 14, 16, 19, 29, 34).[1] --The Twin Buttes deposit, according to Caldwell (8), is in Paleozoic limestones, siltstones, and Mesozoic clastic rocks along the contacts of the dikelike quartz monzonite porphyry contacts. The strongest mineralization is found in the silicated garnetized and chloritized limestones and siltstone; quartzites are only weakly mineralized. Clastics are mineralized on the south, and better copper values occur in contact with the porphyry to the southeast. The quartz monzonite porphyry shows only scattered and weak mineralization. Knaebel (14) noted the host rocks are limestone, silicated limestone or tactite, impure argillaceous limestone and siltstone, arkosic sediments and tuffaceous rocks, quartzites, and intrusive quartz monzonite porphyry. Structurally complex, the sediments are folded and contorted with generally steep dips, stratigraphic unconformities, several systems of faults, and displacements ranging from a few feet to hundreds of feet.

The ore minerals as listed by Knaebel (14) include chalcopyrite, the dominant primary copper mineral; subordinate bornite; and other sulfides including considerable pyrite. Molybdenite occurs sporadically in the primary ore. According to Caldwell (8), the principal oxide minerals are chrysocolla and tenorite or melaconite, with cuprite and native copper locally plentiful; some brochantite and minor malachite are also present. In addition, he reported the occurrence of local sphalerite and galena, abundant magnetite in certain areas, and traces of gold and silver. The secondary sulfide enrichment ore, chalcocite, may occur locally in narrow zones beneath the oxides. Peters (29) noted that the chalcocite blanket was thin and erratic.

As described by Knaebel (14), the deposit is not typically a disseminated porphyry of uniform assay grade; rather the metals were introduced as bunchy

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[1] Underlined numbers in parentheses refer to items in the list of references at the end of this appendix.

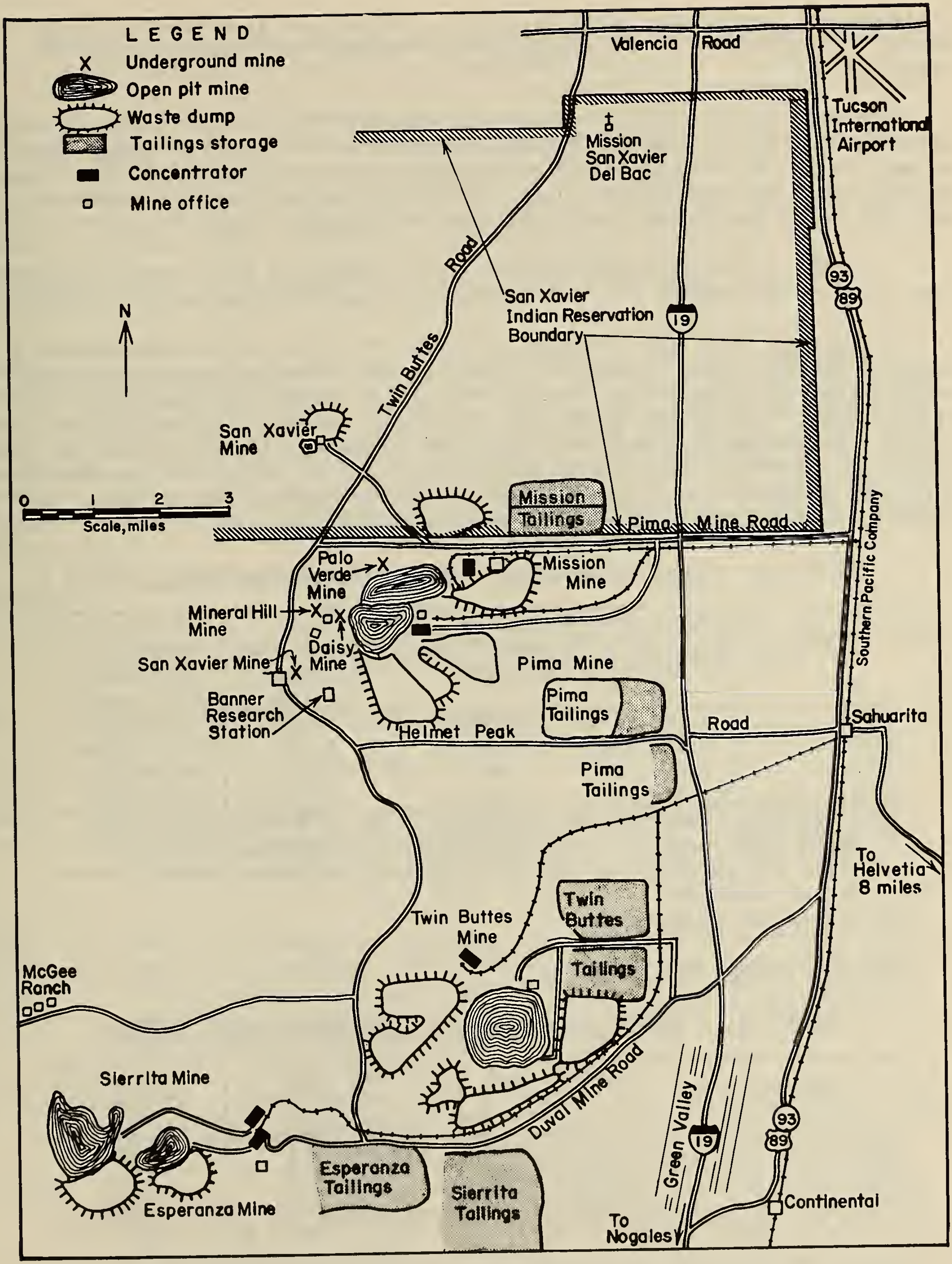

FIGURE E-1. - Pima mining district, Pima County, Ariz.

replacements, as veinlets along fractures, and as more disseminated grains and specks. Distribution of the mineralization depends upon the nature of the host rock.

The Twin Buttes sulfide ore body is overlain from the surface downward by alluvium material ranging in thickness from 400 to 600 feet, by conglomerate as much as 50 feet thick, and by an irregular oxide zone up to 200 feet thick. The oxidized zone occurs in bedrock. The sulfide zone, ranging from 600 to 800 feet below the surface, averages about 0.5 percent copper (8).

In 1970, it was estimated the pit might eventually be as great as 1,800 feet in depth and exceed 1 by 1-1/2 miles in lateral dimensions (17, 19).

Production (1-3, 28).--Copper production from the Twin Buttes operation began in November 1969. Table E-1 shows the ore processed and copper recovered in the concentrates for 1969-72. Table E-2 shows the copper sales for 1970-72 (28). Molybdenum, gold, and silver were recovered as byproducts. Sales of molybdenum concentrates, gold, and silver totaled $1,380,964 for 1970, $2,937,592 for 1971, and $4,426,630 for 1972 (6). In 1971, the Twin Buttes operation produced 1,208,000 pounds of recoverable molybdenum; in 1972, production was 2,119,249 pounds of recoverable molybdenum (2).

TABLE E-1. - Copper production from the Twin Buttes mine, 1969-72

Year	Copper ore processed, tons	Average total copper assay, percent[1]	Average concentrator recovery, percent	Net copper in concentrates produced at mill, pounds
1969[2].......	1,030,654	1.008	67.75	13,574,000
1970........	8,975,192	1.236	80.01	175,752,000
1971........	7,666,009	.988	71.72	106,662,000
1972........	10,738,748	.975	75.50	155,720,000

[1] Ore processed contained an average of 0.02 to 0.04 percent molybdenum. Ore processed in concentrator included some mixed oxidized and sulfide ore. Most of the oxidized copper assay content is not recovered.
[2] November and December only.

Source: Banner Mining Co. (6).

TABLE E-2. - Copper sales from the Twin Buttes mine, 1970-72

Year	Copper sold, pounds	Refined copper and concentrates, gross value[1]	Average price of copper per pound
1970................	99,588,000	$72,347,848	$0.581
1971................	104,078,000	53,447,773	.514
1972................	151,032,000	76,887,027	.509

[1] Does not include value of molybdenum concentrates, gold, and silver.

Source: Pay Dirt. Construction Underway at Twin Buttes Leach Plant (28).

Reserves (2, 6).--In 1968 Anaconda estimated that ore reserves on its leased properties in Pima County, including Twin Buttes, were approximately 292 million tons of sulfide ore averaging 0.88 percent copper and 0.03 percent molybdenum (2). In 1973, Anaconda estimated the ore reserves at Twin Buttes to be 447 million tons of sulfide ore with an average grade of 0.63 percent copper and 0.03 percent total molybdenum, and 55 million tons of oxide ore with an average grade of 1.2 percent total copper (0.82 percent acid soluble). These tonnages were calculated with a 0.2-percent cutoff grade for sulfides and a 0.6-percent cutoff for oxide ore. Approximately 68 percent of the total copper content of the oxide ore is acid soluble; an oxide sulfuric acid leaching plant was under study for the recovery of the acid-soluble copper.

An additional 28 million tons of oxide material with an average grade of 0.49 percent total copper at a cutoff grade of 0.4 percent total copper has been estimated. Widely spaced drill holes and geological evidence indicate an additional 300 million tons of ore with an average grade of 0.8 percent total copper with a cutoff of 0.4 percent copper. Some of this additional ore is in small pockets outside the present operation; some is at great depths. Development of this ore will depend on further geological work, development of suitable mining methods, metallurgical advances, market conditions, and other factors (6).

History

1876	First mining claims at Twin Buttes were reportedly located in 1876, but little mining was done until the early 1900's (9).
1877	Pima mining district was organized (31).
1890	Minnie claim was located (7).
1903, Sept. 8	Twin Buttes Mining and Smelting Co. was organized under Arizona laws with capitalization of $1 million. The capitalization was increased to $1.25 million at $1 par share about 1905, and to $2 million at $1 par share on January 10, 1910 (35).
1905	Twin Buttes Mining and Smelting Co. built a 26-mile standard gage railroad from Tucson to Twin Buttes (31). The railroad was completed to the mines about July 1906 (35). In 1910, 18 miles of this railroad was sold to Southern Pacific Co. and became part of its branch into Nogales, Ariz. (31, 35).
1906	Early production in the area came from the Senator Morgan mine, the Main shaft, the Copper Glance mine, and the Copper King mine. By 1906, the Senator Morgan mine had a 7- by 16-foot, three-compartment shaft about 200 feet deep with 550 feet of lateral workings. The vein was reportedly "25 feet wide with proven depth of 95 feet and proven length of 300 feet carrying sulfide ore of circa 10 percent copper tenor in the bottom workings." The estimate was later reported as excessive. By 1910, equipment from the mine had been moved to the new Main shaft 700 feet to the east.

By 1906, the Copper Glance was opened by a 415-foot shaft with 450 feet of lateral workings. This shaft reportedly passed through 30 feet of gossan and 200 feet of carbonate ore. The crosscut on the 300-foot level intersected 35 feet of marcasite carrying "kidneys" of chalcocite; a crosscut on the 400-foot level encountered soft leached ore. At this time the Copper King mine had a 250-foot shaft, with 250 feet of lateral workings with carbonates in the upper workings and sulfides in the bottom workings. Company properties were reported to have surface dumps containing 10,000 tons; about 1 mile of underground workings had an estimated 50,000 tons of ore blocked out for stoping. The ore averaged about 7 percent copper, 1.85 ounces of silver, and a trace of gold (35). Production of copper and silver from 1906 to 1910 is shown by Weed (36).

1906-13 Twin Buttes Mining and Smelting Co. produced 132,500 tons of ore averaging 5.92 percent copper, mainly from the Senator Morgan mine but some from the Copper Glance (Glance) and Copper King (King) mines (9).

1913 Twin Buttes Mining and Smelting Co. operated the Copper Glance, Senator Morgan, and Copper Queen (Queen) mines. During the year the company shipped 1,500 tons of ore per month to El Paso, Tex. (31).

1913-14 Ed (E. G.) Bush and associates (Bush-Baxter Mining Co.), during leasing of the Senator Morgan mine, produced a few carloads of low-grade ore and then relinquished the lease (9).

1913-18 (ca.) Ed Bush and associates (included William Foy) took a lease and issued a bond on the Glance mine, and then operated the mine under the Glance Mining Co. (13, 31). Glance Mining Co. was reportedly incorporated in 1916. Property of the company was three patented claims held under option from old Twin Buttes Mining & Smelting Co. and a 2-year lease on the Twin Buttes railroad (37).

1917 Ed Bush and associates organized Midland Copper Co. and took a lease and option to purchase for the Copper Glance and Copper Queen mines. The Copper Queen was paid for out of royalties. The lease on Copper Glance was surrendered in 1918, and the mine was idled (9). Ransome (30) reported the Glance and Queen mines were in operation up to the latter part of 1920.

1918 During an 8-month period in 1918, Midland Copper Co. reported production of 4,842 tons of ore, yielding 783,493 pounds of copper and 8,901 ounces of silver. The property was listed as five claims in the Twin Buttes district; a specific mine was not named. Development included an incline shaft 550 feet deep and 400 feet of underground workings (37).

1922-26 Midland Copper Co. reopened the Copper Queen mine under the management of William Foy and shipped ore from 1923 to 1926 (9).

1925-26 Midland Copper Co. purchased the Twin Buttes Railroad in 1925 and took an option on part of the Senator Morgan group, still owned by the Twin Buttes Mining and Smelting Co. (28).

1926 Early production for the mines at Twin Buttes, 1906-26, follows:

Mine	Ore, tons	Copper, percent	Silver, ounces	Copper, pounds	Silver, ounces	Zinc, pounds	Value
Morgan mine,[1] 1906-14......	138,775	5.92	1.92	15,688,237	254,404	NA	$2,035,307
Minnie mine,[2 3 4] 1914-18......	69,605	4.71	1.66	6,192,234	117,798	NA	1,339,804
Queen mine,[5] 1918-26......	78,249	7.054	2.048	10,608,048	153,972	NA	1,747,853
Glance mine[1 6]	124,032	6.721	2.30	15,870,432	271,551	NA	2,786,127
King mine,[1] 1908-13......	8,772	7.35	2.20	1,289,484	19,299	NA	275,020
Total....	419,433	[r]6.1975	[r]2.0189	49,648,435	817,024	1,090,000	[7]8,244,041

[r]--Revised. NA--Not available.
[1] Twin Buttes Mining and Smelting Co.
[2] Bush-Baxter Mining Co.
[3] American Smelting and Refining Co.
[4] Buttes Copper Co.
[5] Midland Copper Co.
[6] Glance Mining Co.
[7] Includes value of zinc, $59,930.

Source: Arizona Department of Mineral Resources. Production Possibilities of Marginal Copper Mines in Arizona (4).

1928 Intermittent operation of four of the nine mines in the Twin Buttes camp to 1928 (presumably from 1905) yielded 388,231 tons of ore averaging 6.19 percent copper and a small tonnage of high-grade oxidized zinc ore. The nine mines included: Senator Morgan group, Copper Glance, Copper Butte, Copper Bullion, Copper King, Copper Queen, Arizona Buttes (Minnie) group, Contention (North Star) group, and Taurus. The Contention lies 3,500 feet south of the Minnie and joins the Senator Morgan group on the southeast (9).

1928-35 Mine idle?

1929 (ca.) Twin Buttes Copper Co. (William Foy) was reported in 1929 as successor to Twin Buttes Mining and Smelting Co. The Twin Buttes Copper Co. acquired the Twin Buttes Copper prospects, including the Senator Morgan. Other properties acquired included Venus, North Star, King, Queen, Glance, and Bullion in the Twin Buttes district. The new company entered on a $500,000 development program, 50 men were employed, and plans were underway for a 600-tpd flotation plant (30).

1936-42 No production.

1942, Aug.-1943, Jan. — A Federal Bureau of Mines investigation of the area was terminated when it became necessary to divert personnel and funds to other work. During the investigation, the Bureau of Mines mapped an area 1,000 by 8,000 feet, including the Copper Glance group of mines and the Contention mine, 2/3 mile southwest of the Minnie mine. Accessible mine workings surveyed included the Minnie, Copper King, and Contention claims (9).

1946 — A report by C. H. Sandberg, "Geophysical Survey in the Twin Buttes District, Pima County, Arizona," described a study of natural-potential measurements and a few direct-current resistivity measurements made in the vicinity of Minnie, Copper Bullion, Copper King, Copper Glance, Copper Queen, and Copper Butte mines (9).

1949? — Properties in the Twin Buttes area consisted of the Senator Morgan group, owned by Twin Buttes Mining and Smelting Co.; the Copper Glance, Copper Butte, Copper Bullion, and Copper King claims, owned by Twin Buttes Mining and Smelting Co., and leased by William Foy until 1948; the Copper Queen claim, formerly owned by Midland Copper Co. (taxes paid by William Foy); the Contention group, owned by William Foy; and the Taurus claim, owned by Gus Gavin (9).

1949 — W. L. Allison of Phoenix, who held a lease and option of the Senator Morgan, Copper Queen, Copper Glance, Copper King, and Minnie mines, called the Twin Buttes district to the attention of Allan Bowman, Banner Mining Co. (7).

1950 — Banner Mining Co. acquired its first claims in the Twin Buttes district (34). Twenty-two claims were obtained at Twin Buttes (13).

In October Banner Mining Co., through a long-term lease and option agreement, gained control of 38 patented Mineral Hill claims located about 7 miles to the north of Twin Buttes (7).

Banner applied for a DMEA loan for exploration at Mineral Hill mine and Copper Glance mine in the Twin Buttes area. The Government contract was to supply the Mineral Hill mine $63,936 and Twin Buttes (Copper Glance) $67,895; the company participated in both projects on an equal basis (15). The projects were to unwater and rehabilitate parts of both mines, sample any unmined reserve, and explore underground by diamond drilling (7).

1951, June 30 — The DMEA loan applied for in 1950 was granted. Banner was to advance capital for work each month, one-half of which would be later reimbursed by DMEA (7).

1953, May — DMEA granted Banner another loan to build a 300-tpd mill and to equip and develop the Mineral Hill mine for production. Total cost of the work was estimated to be $563,665; Banner was to

furnish $90,000 over 12 months. From 1954 to 1957, 12,960,000 pounds of copper was produced for the Government stockpile; the price of the copper was 31 cents per pound. The need for copper during the Korean War was impetus for this DMEA loan (7).

1953, June 30	Exploration work done under the DMEA loan found 500,000 tons of low-grade mill ore at the Mineral Hill mine and 4,000 tons of ore averaging 4.95 percent copper at the Copper Glance mine (7).
1956	Magnetic and electromagnetic surveys over the Twin Buttes property of Banner located several strong anomalies. One of the largest was over the east extension of the Copper Glance mine fault zone. Several initial drill holes, put down to test the anomaly near the Copper Glance shaft, passed through a strong sulfide zone containing pyrite and chalcopyrite at or just above the contact between tactite and what previously was thought to be unmineralized granite. One or two of these drill holes, extended about 100 feet into the granite, encountered disseminated sulfide copper mineralization varying between 0.5 percent and 1 percent copper. High copper prices in 1955 and 1956 prompted Banner to extend drifts on the 525-foot level of the Glance mine eastward under the electromagnetic anomaly. A drift was driven along the fault contact between the limestone and the granite porphyry; some 900 feet of the easternmost part of the drift was in ore averaging about 1.5 percent copper. In 1958 and 1961, surface assessment drilling east of the drift face disclosed further mineralization of substantial thickness (7).
1956-57	Banner shipped some ore from the Copper Glance mine.
1957, June	Twin Buttes (Copper Glance?) mine was temporarily closed because of a severe decline in copper price (5).
1958-63	Banner Mining Co. reported exploration drilling on the Twin Buttes property. In 1961, widespread copper mineralization containing silver and molybdenum values was encountered by surface drilling (5).
1960	Major mining companies acquired blocks of claims adjoining the Twin Buttes property on the east and southeast (5).
1963	By 1963, Banner had assembled a block of 300 to 400 claims covering several square miles (34).
	On March 1, the Anaconda Co. obtained an option agreement to lease all Banner properties in Pima County excluding the Daisy mine, after which Anaconda began their extensive geologic, geophysical, and diamond-drilling activities in the area. The Twin Buttes ore body was partially outlined as a result of this work.

Anaconda obtained Banner's old Mineral Hill mill; the 1,000-tpd mill was remodeled and converted to a 250-tpd pilot mill to test Twin Butte ore. The feed to the mill was sized in the crushing plant, which was also adapted for use as a bulk sampler and for producing pebbles for autogenous grinding tests (14).

1963, Mar. 11-1967, June 27 — Anaconda exploration by surface drilling commenced March 11, 1963. By June 27, 1967, 193 vertical holes had been drilled by Anaconda, ranging in depth from 700 to 2,500 feet, for a total of 321,377 feet completed (14).

1964, Apr. 15 — Anaconda exercised its option and entered into a long-term lease agreement with Banner. Anaconda was to advance funds, without interest, for exploration, development, and mining operations until the mine was in commercial production. Accumulated expenditures will be amortized over future operations of property. Agreement will result in a division of after-tax net income on an approximately equal basis between Banner and Anaconda. In 1964, Banner received $3.6 million for lease bonus, sale to Anaconda of stockpiled oxide ore, some property, and loans by Anaconda. On January 10, 1965, Banner received the first advanced royalty of $1.75 million. At least this much royalty was to be advanced annually for a minimum of 4 years, with provision for continued payments on a prorated basis for up to 2 additional years or until the first mine reaches the production stage. Under the agreement Anaconda exercised its option to lease all mining properties of Banner in Pima County, except the "Daisy Mine Cone." The ores from the Daisy Mine Cone are mined and milled under a custom agreement with Pima Mining Co. Anaconda will lease the mining properties for an initial term of 60 years with an option to renew for such periods as are needed to exhaust the deposits. Banner will receive advanced royalties through January 1971. Banner will be entitled to production royalties based on the net profits of the leased properties when the mine reaches the production stage. The advanced royalties and certain loans, including accrued interest, made by Anaconda are deductible from the production royalties. The lease may be terminated by Anaconda by giving not less than 180 days' notice to Banner (5, 1964 and 1969).

1964, July-1965, Mar. — Anaconda's Twin Buttes No. 1 exploration shaft, collared at a 3,280-foot elevation, was sunk to obtain bulk samples of ore for pilot plant tests and to observe mineralization and geology. The three-compartment exploration shaft was sunk 956 feet through 475 feet of alluvium and 481 feet of blocky porphyry (8, 14).

1965, Feb. 12-1967, Apr. 13 — Pilot milling operations at the Mineral Hill mill commenced with ore from the district for 3 or 4 months; thereafter ore from Twin Buttes was used. A total of 93,793 tons was milled in the test run, including 85,978 tons of ore from Twin Buttes. Laboratory and bench tests were run concurrently at Anaconda's mill at Anaconda, Mont., and at the Mineral Hill mill (14).

1965, Mar.	Exploration that delineated the ore deposit was essentially concluded, and the decision was made to develop the mine. Additional drilling and "underground development" including bulk sampling confirmed the estimated ore grade (14).
1965, Mar. 29-1967, June 19	Drifting and crosscutting on the 880-foot level totaled 16,835 feet. Ore and marginal-grade material was trucked to the pilot mill (14).
1965, July 15-Dec. 31	Removal of alluvium, conglomerate, waste rock, and ore totaled 7,140,460 tons and averaged 81,142 tpd (14).
1965, July 15-1969, Sept.	Anaconda commenced stripping operations. Up to September 1969, the end of the preproduction period, 246,196,216 tons of alluvial overburden had been removed (14).
1965, Aug. 19-1967, July 7	Underground drilling of 73 holes ranging from about 300 to 800 feet deep totaled 45,339 feet (14).
1965, mid	Preconstruction of the mine-mill complex commenced (14, 32).
1966	Removal of alluvium, conglomerate, waste rock, and ore totaled 49,538,259 tons and averaged 148,080 tpd (14). Excavation was begun for the concentrator and related facilities (33). Seven and four-tenths miles of standard gage railroad was built from Southern Pacific Railroad at Sahuarita to the millsite area at Twin Buttes. Under construction were the warehouse, mill shop, mill assay and research laboratory, foundations for seven diesel-gas generators for mine and mill plant power, tire shop, gasoline truck repair facilities, and diamond-drill core storage buildings. A 1-mile extension to the large conveyor system was nearly completed (5).
1967	Removal of alluvium, conglomerate, waste rock, and ore totaled 89,555,730 tons and averaged 267,065 tpd (14). Installation of a complex waste-rock and ore handling system was begun. A 60-inch conveyor system was built to handle 8,500 tph of overburden. The first section of the complex conveyor system was to be operating by the first quarter of 1968 (1, 10-11, 16).

1967, Aug.-1969, Nov. 1	Ralph M. Parsons Co., prime contractor, commenced construction of the ore-processing plant in August (34). Facilities were designed by Parsons Jurden Corp. for a 30,000-tpd capacity with possible expansion later. By December 1, 1968, 600 personnel were engaged on the construction project (33).
1968	Removal of alluvium, conglomerate, waste rock, and ore totaled 70,527,151 tons and averaged 264,147 tpd (14). In August, the first 50-foot bench was developed in rock at an elevation of 2,850 feet; the 2,800-foot bench, December 1968; the 2,750-foot bench, February 1969; and the 2,700-foot bench in April 1969 (34). The West ore and waste conveyor system was completed, and the first phases of the truck stockpile loading-bin project were completed and in operation. The mill reservoir, three wells, water pumping operation, and pipeline components of the plant water system were completed, and operation was begun. The purchasing department, central shops at the millsite, and rock excavation for concentrator were completed during the year (5). Late in the year foundations were begun for the molybdenite concentrate recovery plant and for copper and molybdenum concentrate drying facilities (33).
1969, Jan. 1-Sept. 30	Removal of alluvium, conglomerate, waste rock, and ore totaled 49,747,242 tons and averaged 258,204 tpd. Total removed since July 1965 was 266,508,842 tons (14).
1969, Feb. 10-Mar. 26	A proposal to merge Banner Mining Co. and Newmont Mining Corp. was discussed and terminated (5).
1969, first quarter-1970, Aug.	Anaconda began construction of a 6-tpd pilot plant for evaluating and developing a process for direct reduction of copper sulfide ores into metallic copper, elemental sulfur, silver, gold, molybdenum, and other values. The process, being developed by Anaconda, was known as the Anatread process. Treadwell Corp. of New York, holder of the patents of the process, entered into a joint-venture agreement with Anaconda (20).
1969, Sept.	The first of three sections of the copper concentrator was brought on-stream (5).
1969, Sept. 30	The first significant sulfide ore had been mined on the 2,650-foot level (34). By this date, the approximate end of the preproduction period, the alluvium removed amounted to 246,196,216 tons. Hard rock production totaled 20,312,626 tons; conglomerate and waste rock 7,963,112 tons; oxidized and mixed materials stockpiled for future treatment (much of this material was very low grade)

11,354,844 tons; ore stockpiled for sulfide concentrator 798,750 tons; and ore sent directly to mill 194,000 tons (14). Best single day's performance was February 21, 1969, when 359,000 tons of material was moved by direct haul and the two conveyor systems (19).

1969, Nov. 1 — Shipments of copper concentrates were made to the American Smelting and Refining Co. smelter at Hayden and to the Inspiration Consolidated Copper Co. smelter at Miami, Ariz. (5). Concentrates were also shipped to Magma Copper Co. smelters at Superior and San Manuel (34). No copper was sold in 1969 because after the ore was milled approximately 90 days elapsed before concentrates were smelted and the refined copper was in salable form (5).

1969, Dec. 31 — By yearend Anaconda had expended over $200 million for exploring and developing the Banner properties in Pima County. A total of 1.5 million tons of sulfide ore had been processed during 1969; about 30,000 tons of concentrates containing almost 19 million pounds of copper was produced. Sulfide and mixed sulfide-oxide ores totaling about 1,500,000 tons were stockpiled (5).

1970 — The first full year of production was as follows: 8,975,192 tons of ore, 285,023 tons of concentrate, 175,751,527 pounds of copper, 265,607 pounds of molybdenum, and 1,206,310 ounces of silver (5).

1970, ca. Jan.-July — Treadwell Corp. was constructing an experimental plant in Tucson at a cost of $3 million. The plant was to be used in testing a method for converting sulfide copper into metallic copper by hydrometallurgical means. The plant, to process 6 tons of copper concentrate per day into 2 tons of finished copper, was scheduled for completion July 1970 (38).

1970, Mar. — Sections of the mill were put into operation as completed. During the break-in period, the daily tonnage of ore processed was increased to 23,000, and by late April the mill was reported to have reached designed capacity of 30,000 tpd; the ore contained from 0.5 to 0.7 percent copper and some molybdenum (19, 34).

1970, May — The molybdenum recovery plant commenced operation (34).

1970, June-1971, Mar. 29 — Under discussion was a merger plan among Banner, Rico Argentine, Tintic Standard Mining Co., Consolidated Eureka Mining Co., and Houston Natural Gas. Transactions were terminated (5).

1970, Aug. — The pit was 4,000 by 5,000 feet on the surface and 800 feet deep. Planned size was 9,000 feet long by 6,500 feet wide and 1,000 feet deep (34).

1971 Anaconda reported lower copper production for the year because of the copper strike (see below) and treatment of lower grade ore. A major slide in the pit resulted in the processing of a lower average grade of ore than had been forecast (1, 1971). Reportedly, the slide covered 10 million tons of ore (12). During the year, 7,666,009 tons of ore averaging 0.988 percent copper was processed in the concentrator. This ore was partly oxidized, making it difficult to mill. Copper concentrates totaled 179,707 tons from which 108,594,565 pounds of copper was recovered. A total of 1,208,433 pounds of molybdenum was obtained from molybdenum concentrates. Oxidized ore averaging 0.72 percent copper was mined and stockpiled. The stockpile of oxide ore totaled 25,644,994 tons. Lower production in 1971 was attributed to the August copper strike and to the limitation of smelting capacity by State environmental antipollution regulations. Consequently, the Twin Buttes mill was shut down for 4 weeks in August and 5 weeks during October and November (5).

1971, July 31 Workers at Twin Buttes joined the industrywide copper strike, which began July 1. Twin Buttes was shut down until an agreement was reached about August 27 (21).

1971, Oct. Mill operations were to cease October 1 until the concentrates accumulated during the smelter strike had been shipped. Hayden smelter was unable to take concentrates until after September 13; the company was unable to dispose of them in the United States or abroad. About 25,400 tons of concentrates awaited shipment. Of the hourly work force of 1,250, 125 were temporarily laid off (22).

Anaconda announced a reorganization of personnel and company operations because of severe reversals resulting from the loss of income from Chilean properties. This reorganization was reflected in Arizona when research operations were temporarily closed, including a pilot plant developing a direct reduction process of sulfide ores at the Extractive Metallurgical Research Center at Tucson, and another pilot plant developing a method of beneficiating low-grade copper oxide ores (23).

1971, fall Indications of prolonged additional testing in order to arrive at a workable flowsheet prompted Anaconda to discontinue pilot plant activity on the Anatread process. Under consideration was another hydrometallurgical process which would eliminate smelter pollution (1).

1971, Nov. Anaconda announced plans to increase ore production from an average 28,000 tpd to 32,000 tpd (24).

1972, Aug. Under a three-way proposed agreement involving American Metal Climax, Inc. (AMAX), The Anaconda Co., and Banner Mining Co., AMAX would acquire Banner assets, become a 50-50 partner with Anaconda, and furnish additional capital for enlarging the Twin Buttes

operation. Enlargement of the operation would include the construction of a new plant to treat oxide ore. No decision had been reached on the type of plant, but "it is expected to use sulfuric acid for leaching and electrowinning for recovery of the copper" (25).

1973, Jan. Anaconda announced construction of a new plant to convert copper concentrates into electrolytic copper by a new hydrometallurgical process called the Arbiter Process. The proposed plant, having a capacity of 36,000 tpy of copper, was to be built in Anaconda, Mont., at a cost of $22 million. Compared with the conventional pyrometallurgical process, the Arbiter Process offers the following advantages: (1) Cost is lower, (2) process avoids air pollution, and (3) process is adaptable for small-capacity plants (18).

1973, June AMAX completed acquisition of Banner. AMAX and Anaconda, with a 50-50 percent partnership, formed a new company called Anamax Mining Co. to operate the Twin Buttes mine. Tintic Standard Mining Co., which held 11.33 percent of Banner common stock, was also acquired by AMAX. Other companies involved in the complex merger transaction included Rico Argentine Mining Co., which held 10.5 percent of Banner common stock, and the Consolidated Eureka Mining Co. AMAX and Anaconda estimated an expenditure of about $244 million to expand Twin Buttes, with AMAX reported to have made an initial investment of $93 million. Under the joint venture $60 million would be allocated for building a solvent extraction electrowinning plant, $40 million for open pit development including new transporting and crushing units, and $51 million for expanding the sulfide-ore concentrator. The present concentrator would be expanded from 30,000 tpd to 40,000 tpd, and the oxide plant was to have a 10,000-tpd capacity. Production in 3 years was anticipated to be 120,000 tpy of copper. Each company would market its share of the production. The new company was to develop the unmined northeast ore body, and the entire development program--mine, concentrator expansion, and oxide plant--was expected to require 3 years. Development of the Palo Verde (Mineral Hill area) was to undergo a feasibility study and evaluation, including discussions with ASARCO which owns the adjoining Mission property. The Helvetia properties of Banner have been under geologic and economic evaluation.

Reserves at Palo Verde (Mineral Hill) have been approximated to be 95 million tons of sulfide ore with an average grade of 0.74 percent copper using a 0.35-percent-copper cutoff. The Helvetia properties contain an estimated 320 million tons of sulfide material with an average grade of 0.64 percent copper using a 0.3-percent-copper cutoff, plus additional oxide material. Further exploration was expected (6, 26).

1973, Aug. AMAX announced the formation of a wholly owned subsidiary, AMAX Arizona, Inc., to manage AMAX's 50-percent interest in Anamax (27).

REFERENCES

1. The Anaconda Co. Annual Reports, 1964-71.

2. _____. Prospectus. Nov. 19, 1968, p. 10.

3. Arizona Department of Mineral Resources. Copper Industry; Statistics for (year) Compared With Other Years, Arizona, United States and World (title varies). Phoenix, Ariz., annual publications 1969 through 1972.

4. _____. Production Possibilities of Marginal Copper Mines in Arizona. A report to Leon Henderson, Director, Office of Price Administration and Civilian Supply. Prepared by the Arizona Dept. Mineral Resources at the request of the Arizona Copper Tariff Board. Phoenix, Ariz., 1941, 150 pp.

5. Banner Mining Co. Annual Reports, 1957-71.

6. _____. Proxy Statement. Mar. 13, 1973, pp. 5, 10, 14-15, 52-55.

7. Bowman, A. B. History, Growth and Development of a Small Mining Company. Min. Eng., v. 15, No. 6, June 1963, pp. 42-49.

8. Caldwell, A. B. Twin Buttes--Anaconda's Concept for Mining and Processing a Low-Grade Copper Ore. Min. Eng., v. 22, No. 4, April 1970, pp. 51-66.

9. Cummings, J. B., and T. M. Romslo. Investigation of Twin Buttes Copper Mines, Pima County, Ariz. BuMines RI 4732, 1950, 14 pp.

10. Engineering and Mining Journal. Stripping at Twin Buttes. V. 168, No. 4, April 1967, pp. 91-99.

11. _____. Twin Buttes Solves the Problems of Great Depth, Low Grade, Complex Orebody. V. 171, No. 8, August 1970, pp. 74-78.

12. _____. V. 173, No. 5, May 1972, p. 128 (news note).

13. Kalt, W. D., Jr. Awake the Copper Ghosts; The History of Banner Mining Company and the Treasure of Twin Buttes. Banner Mining Co., 1968, 99 pp.

14. Knaebel, J. B. Development of the Twin Buttes Mine. Pres. to Soc. Min. Eng., AIME, Denver, Colo., Feb. 15-19, 1970, AIME Preprint 70-AO-58, 63 pp.

15. Luff, Paul. The Mineral Industry of Arizona. BuMines Minerals Yearbook 1952, p. 96.

16. Matter, F. S., K. C. Clark, J. A. Hann, S. P. Schuman, and B. J. Blanchard. A Balanced Approach to Resource Extraction and Creative Land Development; Associated With Open-Pit Copper Mining in Southern Arizona. University of Arizona, College of Architecture and College of Mines, Tucson, Ariz., 1974, 85 pp.

17. Mining Magazine. Twin Buttes; Pre-Production Stripping With Belt Conveyors. V. 123, No. 3, September 1970, pp. 182-183, 185-186, 189.

18. Mining Record. Anaconda Will Construct Copper Conversion Plant. V. 84, No. 3, Jan. 17, 1973, p. 1.

19. Pay Dirt. Anaconda's Twin Buttes Mine in Full Production. No. 370, Apr. 27, 1970, pp. 4-10, 20, 22, 24, 26, 28, 30.

20. _____. Anaconda's Work on Anatread Process Is Expanding Metallurgical Frontiers. No. 380, Feb. 22, 1971, pp. 4-6.

21. _____. Copper Strike Winding Down; Late Settlements Clouded by Presidential Freeze. No. 386, Aug. 30, 1971, p. 3.

22. _____. Halt Twin Buttes Milling. No. 387, Sept. 27, 1971, p. 8.

23. _____. Many Changes at Anaconda as President John M. Place Calls Shots. No. 388, Oct. 25, 1971, pp. 10-12.

24. _____. Anaconda Reports Changes in Operations. No. 389, Nov. 29, 1971, p. 6.

25. _____. AMAX To Enter Arizona Mining With Banner and Anaconda. No. 398, Aug. 28, 1972, p. 6.

26. _____. AMAX, Anaconda Set Twin Buttes Expansion as Banner Deal Is Completed. No. 408, June 25, 1973, p. 7.

27. _____. Name Allan Bowman President of AMAX, Arizona. No. 410, Aug. 27, 1973, p. 37.

28. _____. Construction Under Way at Twin Buttes Leach Plant. No. 412, Oct. 29, 1973, p. 8.

29. Peters, W. C. Some Geological Comparisons--Recent Porphyry Copper Discoveries. Min. Cong. J., v. 56, No. 10, October 1970, p. 29.

30. Rand, L. H., and E. B. Sturgis. The Mines Handbook. Mines Information Bureau, Suffern, N.Y., v. 28, pt. 1, 1931, 2026 pp.

31. Ransome, F. L. Ore Deposits of the Sierrita Mountains, Pima County, Arizona. U.S. Geol. Survey Bull. 725-j, 1922, pp. 407-440.

32. Skillings, D. N. Anaconda Prepares Site for Its New Twin Buttes Copper Concentrator. Skillings' Min. Rev., v. 56, No. 24, June 17, 1967, pp. 1, 21.

33. Skillings, D. N., Jr. Twin Buttes Copper Project of Anaconda Co. in Arizona. Skillings' Min. Rev., v. 58, No. 6, Feb. 8, 1969, pp. 1, 4-5, 8.

34. _____. Twin Buttes Project. Skillings' Min. Rev., v. 59, No. 36, Sept. 5, 1970, pp. 1, 4, 5, 12-16.

35. Stevens, H. J. The Copper Handbook. Horace J. Stevens, Houghton, Mich., v. 6, 1906, 1116 pp.; v. 10, 1910-11, 1628 pp.

36. Weed, W. H. Copper Handbook. W. H. Weed, Houghton, Mich., v. 11, 1912-13. 1914, pp. 900-901.

37. _____. The Mines Handbook. W. H. Weed, New York, v. 14, 1920, 1992 pp. (replaced Copper Handbook listed as reference 35).

38. World Mining. Anaconda Seeks Cu Smelting by Hydrometallurgical Method. V. 6, No. 1, January 1970, p. 43.

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